PLANTERS' RECORD

VOL. XL

A quarterly paper devoted to the sugar interests of Hawaii, and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

JANUARY TO DECEMBER

THE HAWAIIAN PLANTERS' RECORD

VOL. XL

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ORGAN OF THE EXPERIMENT STATION OF THE
HAWAIIAN SUGAR PLANTERS' ASSOCIATION

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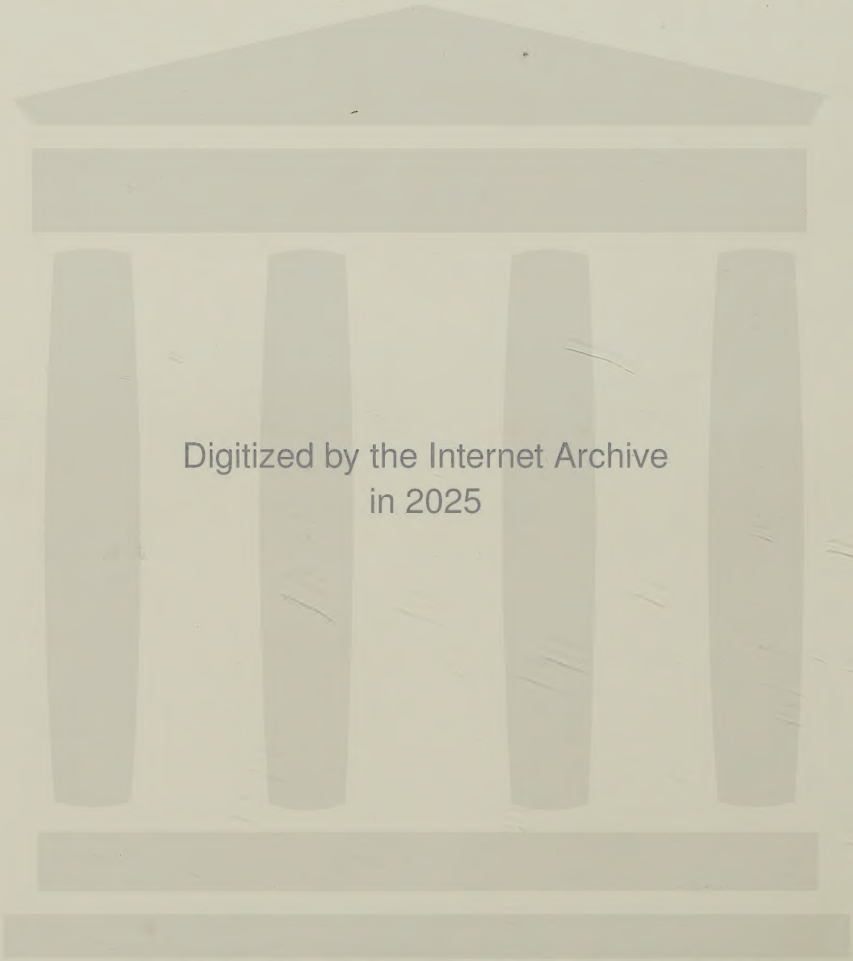
1936



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ILLUSTRATIONS APPEARING ON THE COVERS OF VOLUME XL

FIRST QUARTER

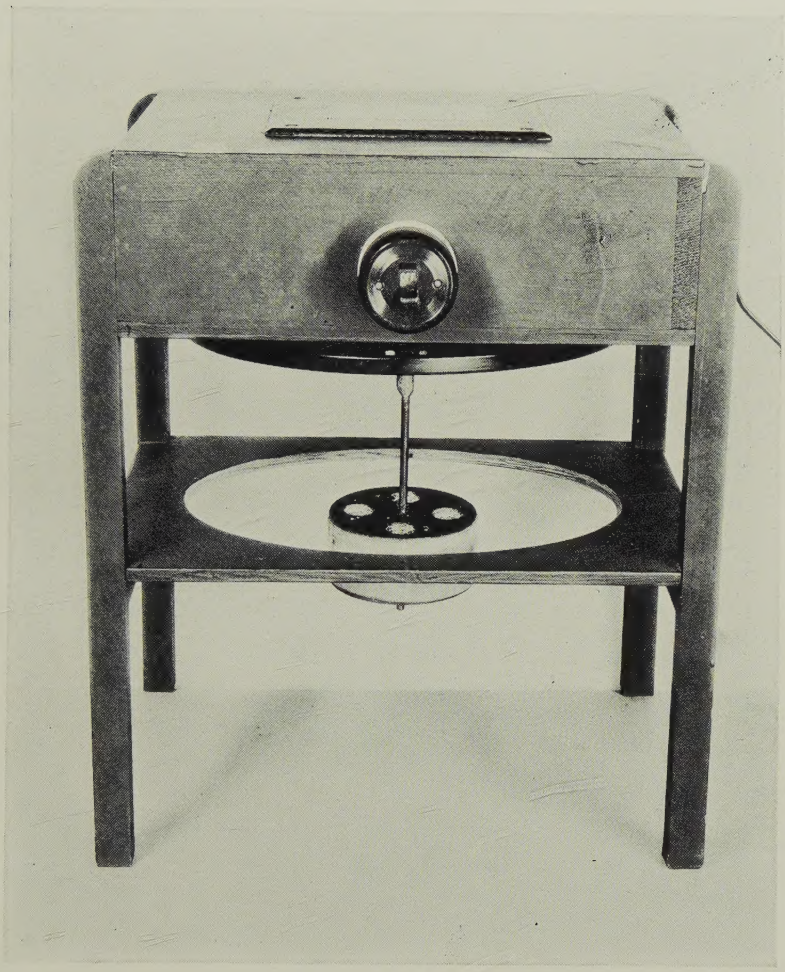
FLOWER OF THE BALSA TREE

Balsa, the lightest wood known, should not be overlooked as a possible crop for idle lands in Hawaii.

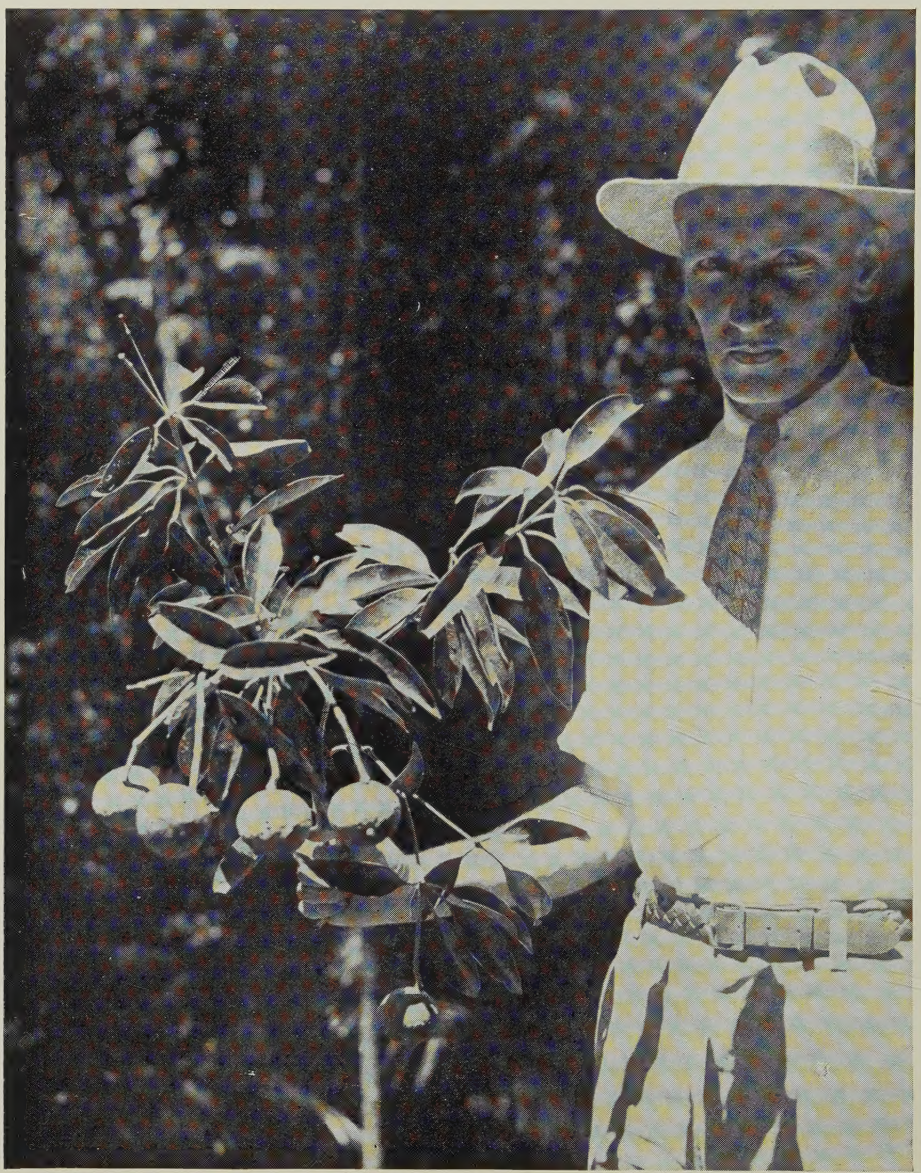
SECOND QUARTER

A few of the large stools of sugar cane exhibited at the Kauai Fair.

The stool directly behind the two girls at the left took first prize in its class and was also named Grand Champion. It is a stool of 30-2417 and was entered by Kekaha Sugar Company, Ltd.



The Experiment Station, H.S.P.A. "Potash Rotator."



A fruiting branch of the Giant Macadamia Nut of North Queensland, exhibited by G. L. Windred, Chief Entomologist of the Colonial Sugar Refining Company. Efforts towards its introduction and establishment in Hawaii are now underway.

THE HAWAIIAN
PLANTERS' RECORD

Vol. XL FIRST QUARTER, 1936 No. 1

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Diagnosing the Status of Available Phosphoric Acid and Potash in Sugar Cane Soils:

Definite soil fertility zones, showing differences in the available supply of phosphate and of potash as determined by the rapid chemical methods of analyses of soil and crusher juice samples, have been located in fields of Pioneer Mill Company, Ltd., that were harvested in 1935. A good relationship was found between the cane yield and the available status of each nutrient in those areas where another limiting growth factor was not dominant. Hence the possibilities for the utilization of the analytical results secured by the rapid chemical tests to develop a sound economic plan of differential fertilization is clearly demonstrated.

Cane-Tonnage, Purity, Soil-Analyses, Juice-Analyses Relationships:

In the analytical data secured by the Pioneer Mill Company, Ltd., during 1935 we have found some very interesting relationships between (a) cane yields and cane quality, (b) cane yields and available phosphate and potash, (c) available phosphate and potash supply in the soil with the soil reaction, (d) available mineral nutrients in the soil and their corresponding uptake by the cane plant as indicated by amounts found in the crusher juice, and (e) phosphate and potash in crusher juice with the corresponding purity of such juice. These relations are apparent in the summarized data which are offered thereafter.

Some Aspects of the Internal Water Economy of the Sugar Cane Plant:

The use of the hand refractometer in a field of H 109 cane at Pioneer Mill Company, Ltd., has provided some evidence that the Brix of that variety suffers a diurnal variation, being relatively high in the late afternoon and low in the morning. This variation is tentatively attributed to variations in the moisture content of the cane, rather than to variations in the actual sugar content.

Although the results were substantiated at the Waipio substation, no convincing verification was secured at the Hilo Variety Station under the environmental and varietal conditions at that place.

The Effect of Nitrogen on Cane Yield and Juice Quality:

This paper gives a rather non-technical account of what happens to the rate of growth, yield, juice quality and chemical composition of H 109 cane when grown with low, medium or very heavy nitrogen fertilization. The experiment is one of a series of studies which has for its ultimate purpose the evaluation of all the factors that concern cane quality.

Biological Control of the Sugar Cane Leafhopper:

A historical account is given of the early appearance and spread of the leafhopper throughout the sugar cane districts of Hawaii and of the search for parasites in other countries and their introduction. An account of each parasite and its value as an enemy of the leafhopper is also given. *Cyrtorhinus mundulus* from Fiji and Australia, a bug which sucked leafhopper eggs, was found to be of greatest importance. There is also an account of many native insects and spiders which assisted in bringing about the ultimate control of the leafhopper.

The Day-Degree in Mauritius:

A brief comment is given on the use of the day-degree in Mauritius.

Diagnosing the Status of Available Phosphoric Acid and Potash in Sugar Cane Soils

By R. J. Borden

Making use of the rapid chemical methods (1) of analyzing soils and crusher juices for phosphoric acid and potash, and of the official methods of the Association of Hawaiian Sugar Technologists (2) for determining Brix and polarization and calculating purity of crusher juices, the field and technical staff of Pioneer Mill Company, Ltd.,* have cooperated in a very thorough and extensive study to determine the status of available phosphoric acid and potash in all fields that were harvested in 1935. The plan and procedure for this study have been presented by Taylor (3) but are given here again in a brief form so that the results reported hereafter may be intelligently studied.

In the procedure as used by Taylor, an attempt is made to choose a field sampling station to represent every five acres from which cane is being harvested. Thus in a 50-acre field, some 10 sampling stations would be selected and distributed over the total area in such a way as to pretty generally "sample" the field. The area of each of these sampling stations is that of 4 or 5 adjacent watercourses occupying from 0.3 to 0.5 acre. These stations are selected and "flagged out" (with a yellow flag at each of the 4 corners) immediately after the cane has been cut and the track line installed nearby so that all cane from the sampling station can be loaded upon cars in an unbroken string. The ticket boy and harvesting luna supervise the loading and mark the cars with an identifying cane ticket and level ditch number so that all concerned are well advised. At the mill, the cane is weighed and a running crusher juice sample of all cane cut from each station is taken for the various juice analyses that are desired. After the cane is loaded, a soil sample is taken from the area of the sampling station. A definite procedure is used to collect this soil sample: in each watercourse of the selected area, starting at a point 10 feet inside the watercourse in the fifth line and similarly in every fifth line therefrom, the top 4 or 5 inches of soil are scraped away from the lower portion of the mauka bank and about 2 handfuls of soil are then dug out and placed in a bucket. When some 20 to 25 of these unit samples have thus been taken up, they are thoroughly mixed together and about 1½ pounds of this well-mixed soil is put into a paper bag and brought to the soil laboratory for the required soil analysis. Later on, before the corner flags have been removed, the area of each sampling station in the field is measured so that its cane weight in tons per acre may be calculated from the weight of cane that was obtained. Sufficient information is taken at this time so that each sampling station can be relocated for future soil sampling in the field.

As a result of this procedure, which has called for the active cooperation of the cutters and loaders, the harvesting and transportation bosses, the yard and scale

* We are greatly indebted to the officials of the Pioneer Mill Company, Ltd., who have made their data available to us for the study which forms the basis of this presentation.

men, the technical staffs of the mill chemist, the civil engineer, and the agriculturist, we have a large body of analytical data which is truly correlative, since cane weights, cane juices, and soil analyses have all been secured from the same identical field areas.

Sampling errors are undoubtedly represented in the data but because there are an adequate number of samples, the influence of such errors is perhaps not such as to seriously affect the averages or to cover up the trends that are apparent. Discrepancies between soil and juice analyses have also occurred and it is quite likely that a verification of the status of the mineral nutrients in the soil, by resampling the specific sampling stations where disagreement is observed, will improve the reliability of the data.

We believe, however, that the analytical data that have been secured show some very definite results which we shall now attempt to point out and to briefly discuss for the various sections of the plantation and for a few of the larger individual fields that are represented in the data.

STUDY No. 1

Relation of Available Phosphate to Cane and Sugar Yields in Field C-2.

No. of Samples Averaged	P_2O_5 in the Soil	P_2O_5 in the Juice	Tons Cane per Acre	Tons Sugar per Acre
23	Doubtful-Low	.035 per cent	66.6	8.28
16	High	.040 per cent	79.1	9.98
39				

The supply of available potash in this field is all medium or high.

Comment: The better cane and sugar yields came from areas that had a "high" supply of phosphate. The status of a few smaller areas in this field needs verification, but in general the area divides itself into the upper half which is well supplied with phosphate, and the lower half which may be deficient. If, as is thought to be the case, this high phosphate supply has resulted from applications of filter cake that were made to this normally low-phosphate soil several years ago, then an inspection of the field-fertility map (Fig. 1) will clearly indicate where future applications of filter cake might be made to best advantage in this field.

STUDY No. 2

Relation Between Phosphate and Potash in the Soil and Juice, and the Cane Yields in Field B-6.

No. of Samples Averaged	P_2O_5 in the Soil	P_2O_5 in the Juice	Cane Yields: Tons per Acre
16	Doubtful	.036 per cent	73.6
12	Medium-High	.054 per cent	85.8
28			

No. of Samples Averaged	K_2O in the Soil	K_2O in the Juice	Cane Yields: Tons per Acre
11	Doubtful-Low	.134 per cent	73.3
17	Medium	.233 per cent	82.4
28			

Comment: Both the potash and the phosphate differences in the soil of this field appear to be related to the cane yields. The juice data substantiate the soil data. The different zones of fertility in this field are quite clearly defined and a differential fertilization would be practicable.

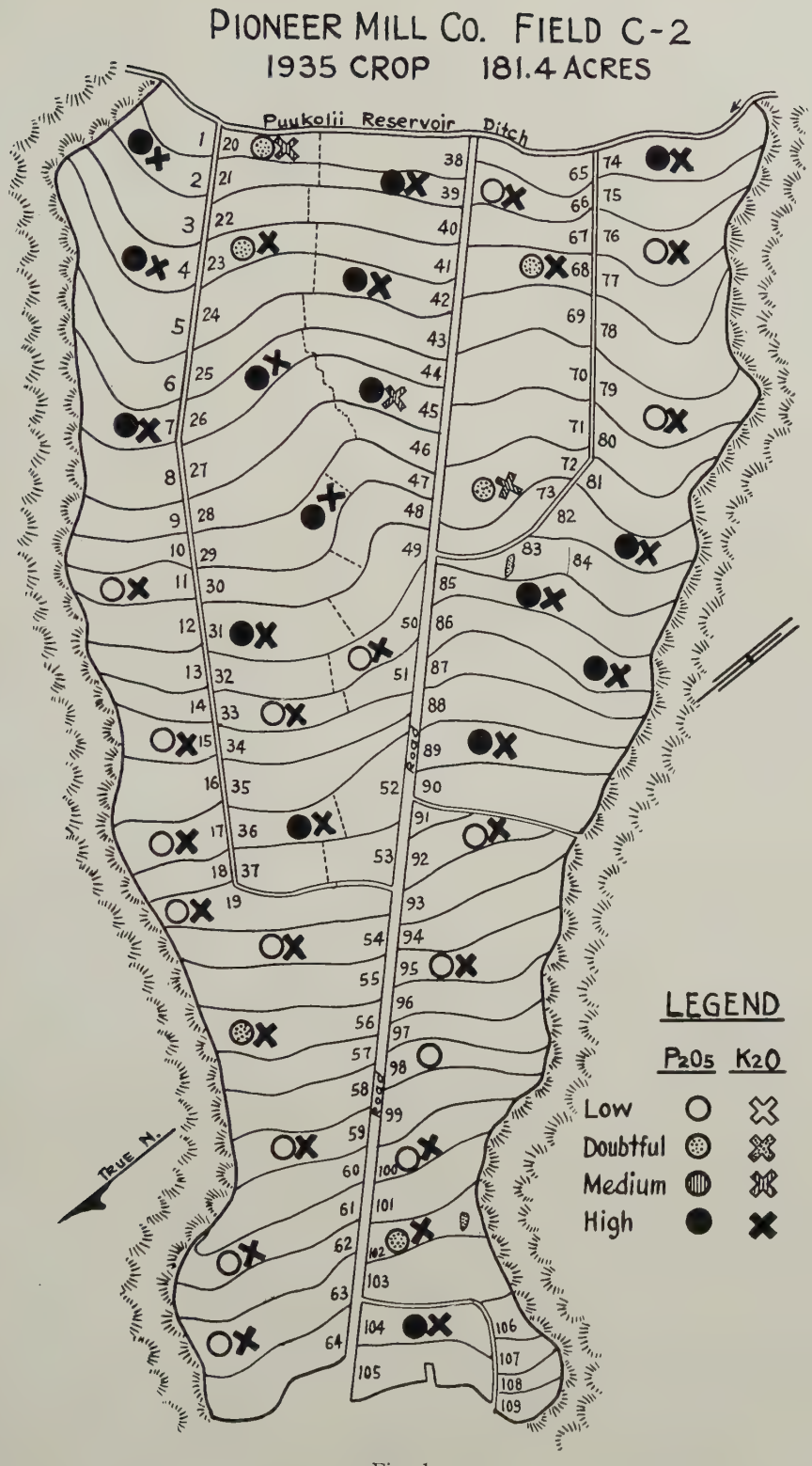

PIONEER MILL CO. FIELD C-2
1935 CROP 181.4 ACRES
Puukolii Reservoir Ditch
Road
Road
TRUE N.
LEGEND
P2O5 K2O
Low
Doubtful
Medium
High

Fig. 1

STUDY No. 3

Relation Between Phosphate and Potash in the Soil and Juice, and the Cane Yields in Field 32.

No. of Samples Averaged		P_2O_5 in the Soil	P_2O_5 in the Juice	Cane Yields: Tons per Acre
Soil	Juice			
13	14	Doubtful-Low	.020 per cent	83.7
17	19	Medium-High	.026 per cent	86.6
—	—			
30	33			

No. of Samples Averaged		K_2O in the Soil	K_2O in the Juice	Cane Yields: Tons per Acre
Soil	Juice			
8	9	Doubtful-Low	.114 per cent	78.6
23	24	Medium-High	.260 per cent	88.2
—	—			
31	33			

Comment: Here we note a possibly greater influence of the potash than of the phosphate supply on cane yields. The zones of the higher and of the lower mineral fertility in this field are quite distinct.

STUDY No. 4

Relation of Potash in the Soil and Juice to Cane Yields in Field 33.

No. of Samples Averaged	K_2O in the Soil	K_2O in the Juice	Cane Yields: Tons per Acre
11	Doubtful-Low	.143 per cent	71.8
19	Medium	.165 per cent	76.2
—			
30			

Comment: A relationship between the available potash and cane yields is indicated here, in spite of the fact that the phosphate supply is low for all samples in this field.

STUDY No. 5

Relation Between Phosphate and Potash in the Soil and Juice, and the Cane Yields in Field 34.

No. of Samples Averaged		P_2O_5 in the Soil	P_2O_5 in the Juice	Cane Yields: Tons per Acre
Soil	Juice			
33	34	Doubtful-Low	.026 per cent	67.9
13	13	Medium-High	.032 per cent	70.1
—	—			
46	47			

No. of Samples Averaged		K_2O in the Soil	K_2O in the Juice	Cane Yields: Tons per Acre
Soil	Juice			
35	35	Doubtful-Low	.160 per cent	68.6
11	10	Medium	.179 per cent	69.7
—	—			
46	45			

Comment: The influence of potash and phosphate on these yields is not very great. Both plant foods appear generally low.

STUDY No. 6

Relation Between Phosphate in the Soil and the Cane Yields in the "C" Fields.

No. of Samples Averaged	P_2O_5 in the Soil	Tons Cane per Acre
23	Low-Doubtful	66.2
42	Medium-High	83.3
65		

Comment: A very definite relation between cane yields and the supply of available phosphate is shown in the "C" fields. All samples were high in potash.

STUDY No. 7

Relation Between Phosphate and Potash in the Soil and the Cane Yields in the "B" Fields.

No. of Samples Averaged	P_2O_5 in the Soil	Tons Cane per Acre
75	Low-Doubtful	75.9
34	Medium-High	77.7
109		

No. of Samples Averaged	K_2O in the Soil	Tons Cane per Acre
36	Low-Doubtful	68.0
73	Medium-High	80.9
109		

Comment: Potash apparently dominates the effect on cane yields in the "B" fields.

STUDY No. 8

Relation Between Phosphate in the Soil and Cane Yields in the "G" Fields.

No. of Samples Averaged	P_2O_5 in the Soil	Tons Cane per Acre
10	Low-Doubtful	72.4
20	Medium-High	76.8
30		

Comment: In the "G" fields, the deficiency of available potash which is mostly low to doubtful, has somewhat limited the full influence of the phosphate on the cane yields.

STUDY No. 9

Relation Between Phosphate and Potash in the Soil and Cane Yields in the "H" Fields.

No. of Samples Averaged	P_2O_5 in the Soil	Tons Cane per Acre
29	Low-Doubtful	78.4
36	Medium-High	77.4
65		

No. of Samples Averaged	K_2O in the Soil	Tons Cane per Acre
33	Low-Doubtful	79.2
32	Medium-High	76.8
65		

Comment: No effect upon cane yields is indicated by the amounts of available phosphate and potash found in the "H" fields. This suggests that (a) other growth factors than these mineral nutrients have a more effective influence on cane yields, and (b) an adjustment of fertilizer applications may not be expected to raise the average cane yields here until other limiting factors are corrected.

STUDY No. 10

Relation Between Phosphate in the Soil and Cane Yields in the "F" Fields.

No. of Samples Averaged	P_2O_5 in the Soil	Tons Cane per Acre
44	Low-Doubtful	83.5
7	Medium-High	75.0
51		

Comment: An effect of the available phosphate upon the cane yields is not apparent in the "F" fields where potash is apparently deficient. (Samples all show low to doubtful potash.)

STUDY No. 11

Relation Between Phosphate and Potash in the Soil with Cane Yields in the "MA" Fields.

No. of Samples Averaged	P_2O_5 in the Soil	Tons Cane per Acre
7	Low-Doubtful	65.2
14	Medium-High	75.2
21		

No. of Samples Averaged	K_2O in the Soil	Tons Cane per Acre
6	Low-Doubtful	66.1
15	Medium-High	74.2
21		

Comment: The higher cane yields in the "MA" fields are quite definitely related to the available supply of both phosphate and potash.

STUDY No. 12

Relation of Phosphate and Potash in the Soil to Cane Yields in the Honokowai Fields.

No. of Samples Averaged	P_2O_5 in the Soil	Tons Cane per Acre
164	Low-Doubtful	75.0
44	Medium-High	80.3
208		

No. of Samples Averaged	K_2O in the Soil	Tons Cane per Acre
60	Low-Doubtful	72.2
149	Medium-High	77.7
209		

Comment: A small, but yet rather definite, influence of both phosphate and potash upon cane yields is noted in the Honokowai fields.

STUDY No. 13

Relation of Phosphate and Potash in the Soil to Cane Yields in the "LB" Fields.

No. of Samples Averaged	P_2O_5 in the Soil	Tons Cane per Acre
26	Low-Doubtful	68.1
26	Medium-High	66.1
52		

No. of Samples Averaged	K_2O in the Soil	Tons Cane per Acre
42	Low-Doubtful	62.9
10	Medium-High	74.9
52		

Comment: In the "LB" fields, potash apparently exerts a greater effect on cane yields than phosphate.

STUDY No. 14

Relation of Potash in the Soil to Cane Yields in the "LC" Fields.

No. of Samples Averaged	K_2O in the Soil	Tons Cane per Acre
8	Low-Doubtful	64.5
40	Medium-High	71.5
48		

Comment: In the "LC" fields where the supply of phosphate was uniformly high, available soil potash is apparently a cane yield-effect factor.

STUDY No. 15

Relation of Phosphate and Potash in the Soil to the Cane Yields Secured in the Olowalu Section.

No. of Samples Averaged	P_2O_5 in the Soil	Tons Cane per Acre
13	Low-Doubtful	68.7
68	High	75.0
81		

No. of Samples Averaged	K_2O in the Soil	Tons Cane per Acre
31	Low-Doubtful	72.9
50	Medium-High	73.8
81		

Comment: The influence of available soil phosphate on cane yields appears to be a greater factor than the influence of potash in the fields at Olowalu.

Conclusion:

The data studied are reliable and adequate; hence the conclusions that are drawn can be sound if they have been properly deduced.

Rather definite zones with mineral fertility differences—i.e., of high and medium phosphate, of doubtful and low phosphate, of high and medium potash, and of doubtful and low potash—have been located within many of the fields. The fertility status

in these zones is in most instances directly related to the sugar cane tonnage that was harvested from them.

Wherever this direct relationship between cane tonnage and available mineral nutrients is found, it suggests that a plan of differential fertilization can be employed to (a) build up the available nutrient supply in the "low-doubtful" areas, and thereby raise the average cane yield for the field, and (b) save money that would ordinarily be expended for fertilizer for application on the "medium-high" areas, since our previous studies have definitely indicated that a yield response to either phosphate or potash fertilizer is not likely to be secured where the supply of these fertilizers in our cane soils in indicated as "high" by our rapid chemical methods of analyses. However, when the relationship between the cane yields and the supply of available nutrients is not found, it may be questionable whether we can raise the average cane yield for such a field, by any adjustment of the fertilization, until the more dominant limiting growth factor has been ascertained and corrected.

Literature Cited

(1) Hance, F. E., 1935. Report of the Chemistry department, Report of the Committee in Charge of the Experiment Station, H. S. P. A., pp. 76-88.
(2) Chemical Control for Cane Sugar Factories, 1931. Ass'n of Haw'n Sugar Tech., 143 pp.
(3) Taylor, H. J. W., 1935. A procedure for sampling cane juice and soil as used at Pioneer Mill Company, Ltd., The Hawaiian Planters' Record, Vol. XXXIX, pp. 109-112.

Addenda:

In using the rapid chemical methods for determining the available status of phosphoric acid and potash in soils, four qualitative groupings or classes are used, e. g., "High," "Medium," "Doubtful" and "Low." For those who would prefer to use "parts per million" or "pounds per acre-foot of soil," the following table is offered.

CLASS	PHOSPHORIC ACID (1)		POTASH (2)	
	P. P. M.	Pounds per Acre-foot	P. P. M.	Pounds per Acre-foot
Low	Less than 8	Less than 20	Less than 70	Less than 175
Doubtful	8 to 15	20 to 38	70 to 140	175 to 350
Medium	15 to 40	38 to 100	140 to 280	350 to 700
High	More than 40	More than 100	More than 280	More than 700

(1) Soluble in a dilute solution of hydrochloric acid during a period of one-half minute.
(2) Soluble in a dilute acid solution of sodium acetate during a period of one-half minute.

Some Interesting Cane-Tonnage, Purity, Soil-Analyses, Juice-Analyses Relationships

By R. J. Borden

The analytical data that were gathered by the technical staff of the Pioneer Mill Company, Ltd., from soil and crusher juice samples collected in connection with their efforts to determine the status of available phosphate and potash in their sugar cane lands, have afforded an excellent opportunity to determine several relationships that exist between the various analyses that were made. We are privileged* to offer herewith a summary of several studies that we have made from these data.

In presenting these studies from this analytical work, we have assumed various arithmetic groupings or various classes for one of the factors concerned, and thereafter have averaged the related figures for the other factor. It appeared impractical to add an indefinite number of regularly spaced arithmetic groupings to accommodate some very few cases; hence, our extreme groupings, which may be indicated as "Below .....," or "Above .....," are apt to contain the more grossly erratic figures which often result from sampling and analytical errors, and the averages concerned with these extreme groupings must be interpreted rather carefully, if they are used at all.

The averages are presented without their probable errors at this time, since it is assumed that we are interested in the trends and general correlations, rather than in arriving at the significance attached to the specific amounts of difference observed. A short comment concerned with our interpretation of the summarized data is offered with each individual study.

We believe that these data have shown some rather definite results, which we suggest are as follows:

(1) That the higher cane yields had a poorer quality ratio than the average yields, but that this fact in itself may be of little economic importance.

(2) That a higher content of both available phosphate and available potash was found in the neutral-to-slightly-alkaline soils than in the acid soils.

(3) That there was a direct relationship between the available phosphate in the soil and the percentage of phosphate found in the crusher juice of cane grown on such soil; similarly, that this direct relationship occurred between available soil potash and the crusher juice potash.

(4) That *both* phosphate and potash in the crusher juice showed an inverse relationship to the purity of this juice; this same relationship also holds for quality ratio.

(5) That sugar cane yields were, to a large degree, directly related to the supply of available phosphate, when potash was not a limiting factor.

(6) That sugar cane yields were also directly related to the supply of available potash, when phosphate was not a limiting growth factor.

Hence, without further discussion, we offer these summarized data for six studies.

---

* By permission of the Pioneer Mill Company, Ltd.

STUDY No. 1

Relation of Cane Yields to Quality Ratio.

No. of Samples Averaged		Tonnage Class	Tonnage Group	Q.R.		Calculated Probable Sugar Yield	
11		35 - 40.4		7.3		5.1	
17		40.5 - 45.4		7.7		5.5	
19		45.5 - 50.4		7.8		6.1	
40		50.5 - 55.4		7.7		6.8	
63	(150)	55.5 - 60.4	(under 60 TCA)	7.7	(Avg. 7.6)	7.5	(Avg. 6.2)
85		60.5 - 65.4		7.6		8.2	
99		65.5 - 70.4		7.7		8.7	
115		70.5 - 75.4		7.5		9.7	
110	(409)	75.5 - 80.4	(60-80 TCA)	7.6	(Avg. 7.6)	10.2	(Avg. 9.2)
95		80.5 - 85.4		7.9		10.4	
54		85.5 - 90.4		7.7		11.4	
47		90.5 - 95.4		8.0		11.5	
37	(233)	95.5 - 100.4	(80-100 TCA)	7.9	(Avg. 7.9)	12.3	(Avg. 11.4)
16		100.5 - 105.4		8.2		12.5	
14		105.5 - 110.4		8.0		13.4	
14		110.5 - 115.4		8.3		13.6	
9		115.5 - 120.4		9.2		12.8	
15	(68)	Above 120.4	(over 100 TCA)	8.2	(Avg. 8.4)	14.9	(Avg. 13.4)

Total 860

Comment: The higher cane yields have generally resulted in a poorer quality ratio. From the calculated probable sugar yields, however, it would seem doubtful that this relationship is a factor that has adversely affected the economics of the sugar production, since the indicated larger sugar tonnages that are associated with the larger cane yields would have more than sufficient value to pay for the harvesting and milling costs on the extra cane tonnage that would be handled.

STUDY No. 2

Relation of Phosphate and Potash in the Soil to the pH of the Soil.

No. of Samples Averaged	Soil P_2O_5 Group	pH of Soil
314	Low	6.4
176	Doubtful	6.4
99	Medium	6.6
343	High	7.0

Total 932

No. of Samples Averaged	Soil K_2O Group	pH of Soil
205	Low	6.3
165	Doubtful	6.5
414	Medium	6.7
148	High	7.0

Total 932

Comment: Apparently there is a somewhat greater availability of phosphate and potash in neutral than in slightly acid soils.

STUDY No. 3

Relations of (1) phosphate in the soil to phosphate in the crusher juice, and (2) potash in the soil to potash in the juice.

No. of Samples Averaged	P_2O_5 in Soil	Per Cent P_2O_5 in Juice
290	Low	.025
157	Doubtful	.029
99	Medium	.033
337	High	.042
Total 883		

No. of Samples Averaged	K_2O in Soil	Per Cent K_2O in Juice
198	Low	.155
161	Doubtful	.179
385	Medium	.253
147	High	.320
Total 891		

Comment: A definite positive relationship is shown between both phosphate and potash in the soil, and phosphate and potash in the juice.

On the basis of data obtained in this study, we may make a suggestion with regard to a tentative group classification for the various amounts of phosphate and potash that were found in the crusher juices. For the time being and in lieu of better criteria, we suggest that the following percentage values from crusher juices be used for the group classifications indicated. (This classification is for H 109 cane grown at Pioneer Mill Company, Ltd., and may not be reliable for other cane varieties or for H 109 grown under different conditions.)

Group Classification (To designate status of available nutrients)	Per Cent P_2O_5 in the Crusher Juice	Per Cent K_2O in the Crusher Juice
Low	.025	.15
Doubtful	.030	.20
Medium	.035	.25
High	.045	.35

It is thought that it will not be necessary to adjust these percentages for differences in purity, since the two following progressive relations are thought to be effective:

(1) Low soil-nutrient availability = low cane yields = high purity = low percentage of nutrient in juices;
(2) High soil-nutrient availability = high cane yields = low purity = high percentage of nutrient in juices.

Thus a low percentage in the juice would be apt to indicate a low availability in the soil, and a high juice content, a high soil availability. A low availability in the soil should result in low cane yields, which in turn would tend to have a higher purity, and this higher juice purity would most likely be associated with a low mineral con-

tent in such juice. Similarly a high availability in the soil should give high cane yields which would tend to have a low juice purity, and this low purity could be due to its high mineral content. Data showing major deviations from this relationship might be open to question and need further verification.

However, if it should be found desirable to adjust these percentages for differences in purity, such adjustment should be made from a basic purity of 87, which was the average juice purity of the data used in compiling these group classifications. Thus for purities below 87, the percentage standards used above would need an upward revision, while for purities above 87, these percentages would be slightly less than we have suggested.

STUDY No. 4

Juice Purity Relationships.

A. Relation of crusher juice purity to the per cent phosphate in the juice.

No. of Samples Averaged	Purity of Juice	Per Cent P_2O_5 in Juice
13	77.1 - 78.9	.048
17	79.0 - 80.9	.044
42	81.0 - 82.9	.046
113	83.0 - 84.9	.042
203	85.0 - 86.9	.036
260	87.0 - 88.9	.029
191	89.0 - 90.9	.027
28	Above 91	.028
Total 867		

Comment: The relationship of phosphate in the crusher juice of cane to its purity is quite clear, i.e., with increased purity there was less phosphate in the juice.

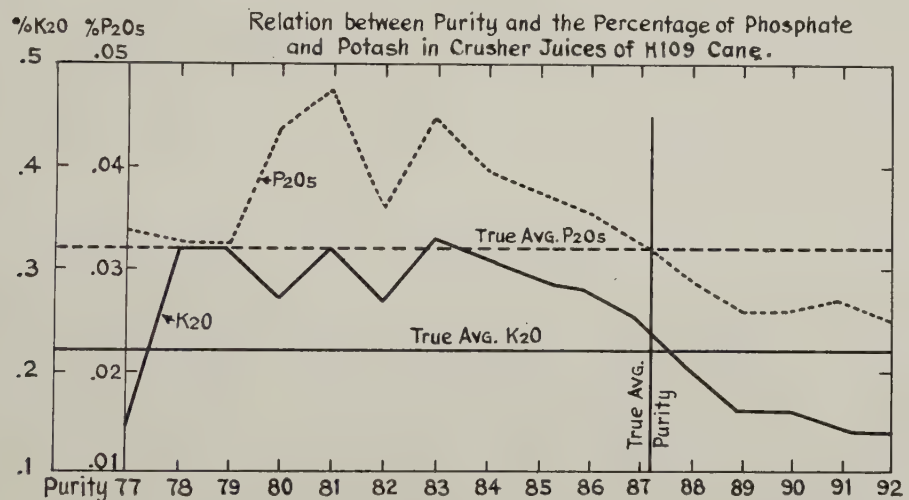
B. Relation of juice purity to the per cent potash of the juice.

No. of Samples Averaged	Purity of Juice	Per Cent K_2O in Juice
13	77.1 - 79	.356
12	79.1 - 81	.331
48	81.1 - 83	.289
108	83.1 - 85	.294
211	85.1 - 87	.266
259	87.1 - 89	.199
178	89.1 - 91	.157
27	Above 91	.132
Total 856		

Comment: As has been found in previous studies of this nature, we here note the association of a high potash content of crusher juice with the lower purities, and a low potash content with the higher purities.

C. Average phosphate and potash content of *H 109 juices only,* at different purities.

No. of Samples Averaged			Per Cent K_2O	Per Cent P_2O_5
K_2O	P_2O_5	Purity	in Juice	in Juice
1	1	77	.150	.034
2	2	78	.317	.033
2	2	79	.318	.033
3	3	80	.265	.044
16	15	81	.321	.048
15	15	82	.274	.036
25	25	83	.330	.045
34	34	84	.312	.040
76	76	85	.287	.038
101	101	86	.278	.036
133	133	87	.248	.033
117	117	88	.203	.029
133	133	89	.164	.026
88	89	90	.156	.026
52	53	91	.138	.027
11	11	92 and above	.143	.025
Totals 809	810			
True Avg.		87.2	0.224	0.032



Comment: This study of the H 109 cane juices only, shows a direct relationship which has not always been generally recognized, i.e., the similar negative correlation between phosphate and potash with purity. Thus *both* phosphate and potash in the crusher juice show decreased amounts with the increasing purities, and vice versa.

D. Relation of phosphate in soil to quality ratio.
(Samples were included only if the potash in the same area was high.)

No. of Samples Averaged	P_2O_5 in Soil	Q.R.
16	Low	7.8
13	Doubtful	7.0
2	Medium	8.0
114	High	8.7
Total 145		

E. Relation of potash in soil to quality ratio.
(Samples were included only if the phosphate in the same area was high.)

No. of Samples Averaged	K_2O in Soil	Q.R.
40	Low	7.9
41	Doubtful	8.1
139	Medium	8.8
114	High	8.7
Total 334		

Comment: There appears to be a direct relationship between the quality ratio of the cane juice and both the available phosphate and potash in the soil upon which the cane was grown.

STUDY No. 5

Available phosphate—cane tonnage relationships.
A. Relation of phosphate in soil to cane yields.
(Only those samples which were *high in potash* are included in this table.)

No. of Samples Averaged	P_2O_5 in Soil	Tons Cane per Acre
25	Low	68.2
9	Doubtful	73.6
2	Medium	72.6
134	High	85.4
Total 170		

Comment: In those soils which were well supplied with potash, we note that (*a*) the heavier tonnages of cane are affiliated with the soils that show "high" P_2O_5, and (*b*) the poorer cane tonnages come from the soils that show a "low" phosphate supply.

B. Relation of phosphate in soil to cane yields, *in fields irrigated by pump water.*
(Only those samples which were *high in potash* are included in this table.)

No. of Samples Averaged	P_2O_5 in Soil	Tons Cane per Acre
16	Low	64.8
4	Doubtful	66.1
129	High	85.2
Total 149		

Comment: In this group of fields which were irrigated with pump water and in which the supply of potash in the soil was high, we find that the larger cane yields are also associated with "high" phosphate.

C. Relation between soil phosphate and cane yields, *when the supply of soil potash is low.*

No. of Samples Averaged	Soil P_2O_5	Tons Cane per Acre
96	Low	71.7
51	Doubtful	78.5
11	Medium	68.1
39	High	72.3
Total 197		

Comment: The effect of the availability of soil phosphate upon cane yields is not definite when the supply of soil potash is low. Potash is evidently a limiting growth factor.

D. Relation of phosphate in the juice to cane yields.

(Samples were included only if the soil sample from the same area was *high in potash.*)

No. of Samples Averaged	Per Cent P_2O_5 in the Juice	Tons Cane per Acre
8	Below .020	76.7
24	.020 - .029	80.7
36	.030 - .039	79.6
43	.040 - .049	88.3
25	.050 - .059	87.6
20	Above .060	78.6
Total 156		

Comment: Generally greater cane yields are found here associated with crusher juices containing more than .04 per cent phosphate than where less than this amount is present.

STUDY No. 6

Available potash — cane tonnage relationships.

A. Relation of cane yields to potash in soil.

(Only those samples which were *high in phosphate* are included in this table.)

No. of Samples Averaged		Tonnage Class	Tonnage Group	K_2O in Soil Lbs. per Acre-Foot	
7		35 - 40.4		286	
8		40.5 - 45.4		394	
9		45.5 - 50.4		297	
12		50.5 - 55.4		223	
Total 18	(54)	55.5 - 60.4	(Under 60 TCA)	463	(Avg. 333)
26		60.5 - 65.4		411	
32		65.5 - 70.4		520	
42		70.5 - 75.4		539	
Total 29	(129)	75.5 - 80.4	(60 to 80 TCA)	510	(Avg. 495)
42		80.5 - 85.4		530	
15		85.5 - 90.4		460	
17		90.5 - 95.4		565	
Total 14	(88)	95.5 - 100.4	(80 to 100 TCA)	602	(Avg. 539)
13		100.5 - 105.4		556	
14		105.5 - 110.4		382	
16		110.5 - 115.4		658	
8		115.5 - 120.4		647	
Total 4	(55)	120.4	(Over 100 TCA)	638	(Avg. 576)
Total 326					

Comment: Where available soil phosphate was not a limiting growth factor, the larger cane tonnages were associated with the larger amounts of potash in the soil.

B. Relation of cane yields to potash *in the soil of fields irrigated by pump water.*
(Only those samples which were *high in phosphate* are included in this table.)

No. of Samples Averaged		Tons Cane per Acre		K_2O in Pounds per Acre-Foot	
6		40 - 45.4		338	
7		45.5 - 50.4		318	
9		50.5 - 55.4		392	
Total 11	(33)	55.5 - 60.4	(Under 60 TCA)	360	(Avg. 352)
20		60.5 - 65.4		389	
20		65.5 - 70.4		455	
34		70.5 - 75.4		549	
Total 23	(97)	75.5 - 80.4	(60 to 80 TCA)	578	(Avg. 493)
32		80.5 - 85.4		568	
12		85.5 - 90.4		498	
13		90.5 - 95.4		613	
Total 11	(68)	95.5 - 100.4	(80 to 100 TCA)	530	(Avg. 552)
47	(47)	Above 100.5	(Over 100 TCA)	645	(645)
Total 245					

Comment: The larger cane yields were associated with the larger amounts of potash in the soil of this group of fields in which the supply of phosphate was high.

C. Relation of soil potash to cane yields.
(Only those samples which were *high in phosphate* are included in this table.)

No. of Samples Averaged	K_2O in Soil	Tons Cane per Acre	
38	Low	73.0	
42	Doubtful	68.2	(Avg. 70.6)
142	Medium	77.4	
114	High	86.3	(Avg. 81.9)
Total 336			

Comment: The average cane tonnage from the "high-medium" potash group is considerably greater than from the "low-doubtful" potash group.

D. Relation between soil potash and cane yields, *when soil phosphate is low.*

No. of Samples Averaged	Soil K_2O	Tons Cane per Acre
96	Low	71.7
59	Doubtful	74.3
129	Medium	77.2
17	High	69.7
Total 301		

Comment: When available phosphate was low, the influence of the supply of available potash on cane yields is not as clearly shown as when the phosphate supply was high.

E. Relation of potash in juice to cane yields.
(Samples were included only if the soil sample from the same area was *high in phosphate.*)

No. of Samples Averaged	Per Cent K_2O in the Juice	Tons Cane per Acre
4	Below .100	68.3
52	.100 - .200	73.4
95	.201 - .300	78.6
158	.301 - .400	81.7
18	Above .400	69.5
Total 327		

Comment: Excluding the two extreme groupings, it would appear that the "Per Cent K_2O in the Juice" had a direct influence on the cane yields.

Some Aspects of the Internal Water Economy of the Sugar Cane Plant

By H. A. Wadsworth

Recent irrigation studies with the sugar cane plant in Hawaii (10) (13) have demonstrated that rate of cane growth, as ordinarily determined, is independent of soil moisture until the soil moisture has fallen to the permanent wilting percentage after which growth, as measured by elongation, is severely handicapped and soon ceases. Without more evidence than this, one is liable to draw conclusions which are not only unjustified but may be entirely misleading.

For example, since the plant at adequate soil moisture contents shows no sign of moisture scarcity in its growth response, one might conclude that sugar formation is proceeding at its maximum rate, an assumption which may or may not be true, but is certainly not demonstrated by the evidence. Or one may assume that the cells of the cane plant are completely turgid whenever the soil moisture is above the permanent wilting percentage but quickly shows signs of saturation deficit when the soil moisture falls below that critical value. Recent studies seem to indicate that such a conclusion is decidedly unsound.

The purpose of the present paper is to present the evidence which indicates that the sugar cane plant, grown in the hot, dry environment common to the irrigated areas of Hawaii, suffers a diurnal change in moisture content and to emphasize the significance that this inadequately appreciated phenomenon may have upon sugar formation.

Brix as a Measure of the Moisture Content of Cane

The hand refractometer has long been popular as a device for measuring variations in the concentration of soluble material in the cell sap of cane. It is to be noted, however, that an increase in the refractive index of the solutions, which is what the device actually measures, may be due to either an increase in the quantity of sugar per unit mass of water, or to a decrease of water per unit mass of sugar. If it may be assumed that the actual amount of sugar in a specific joint is not subject to large and diurnal variations but remains practically constant over limited periods of time, the refractometer becomes a promising tool in measuring variations in the moisture content in the stick.

Brix Observations at Pioneer Mill Company, Ltd.

Opportunities for testing the refractometer in this field of usefulness were offered by Pioneer Mill Company, Ltd., during the summer of 1935. Ten sticks in the upper ten lines of a watercourse plot were selected at random in the early morning. No stick so selected was subsequently discarded unless severe damage, from one cause or another, was noted during the sampling operation. Each stick

so selected was sampled for refractometer Brix in three places. The first of these was in the bottom third of the stick, the second in the middle third and the last in the top third and just below the lowest firmly attached leaf sheath.

The same procedure was followed late in the afternoon, ten sticks again being chosen at random. Sticks previously punctured were avoided.

The sequence outlined above was followed daily for the twelve days between July 15 and July 26 inclusive. The cane was variety H 109, about thirteen months old. The area sampled was in field B-4.

The results secured are tabulated in Table I.

TABLE I

Hand Refractometer Brix Readings, Morning and Afternoon Observations
Variety: H 109
Pioneer Mill Company, Ltd.
Field B-4

(Reported Brix is the numerical average of 10 sticks selected at random in a small area)

	Bottoms		Middles		Tops	
Date 1935	AM	PM	AM	PM	AM	PM
July 15		19.7		18.1		15.6
16	18.4	18.4	17.3	17.7	14.7	14.8
17	19.7	20.0	18.9	17.3	14.8	15.5
18	17.5	19.2	16.4	18.3	14.1	14.9
19	18.7	20.3	18.1	19.7	15.4	17.1
20	19.2	19.4	18.9	19.3	17.2	15.9
21	17.8	18.3	17.2	18.2	15.0	14.3
22	17.7	20.3	17.1	19.8	14.7	17.0
23	19.4	19.6	18.1	19.5	15.5	15.8
24	19.1	18.9	18.7	18.5	16.8	15.2
25	17.7	18.5	16.9	18.2	15.2	15.8
26	19.3	19.6	18.7	18.8	15.9	17.7
Avg.	18.6	19.4	17.8	18.6	15.4	15.8

If it be assumed, as suggested above, that the actual quantity of sugar involved remains constant, the averages in Table I indicate that the moisture content in the cane under observation suffers a diurnal fluctuation, being highest (Brix lowest) in the morning and lowest (Brix highest) in the late afternoon. Moreover, the difference seems greater in the bottoms and middles than in the tops.

A closer inspection of the data indicates that on only one day, July 24, was the Brix, in the bottom section, lower in the afternoon than in the morning. The same situation is to be noted in both middles and tops on the same day. It is interesting to note that a light shower was reported for that day. Attention is once more directed

to the physiological significance of light showers and dews upon the sugar cane plant (14).

As has been noted, only one day is reported during which the Brix in the bottoms declined during the day. But two such cases are noted for the middles and three for the tops. Apparently the cyclic relation suggested above becomes less positive as the point of sampling moves up the stick. The point is illustrated in Fig. 1, which is simply a graphical presentation of the data in Table I.

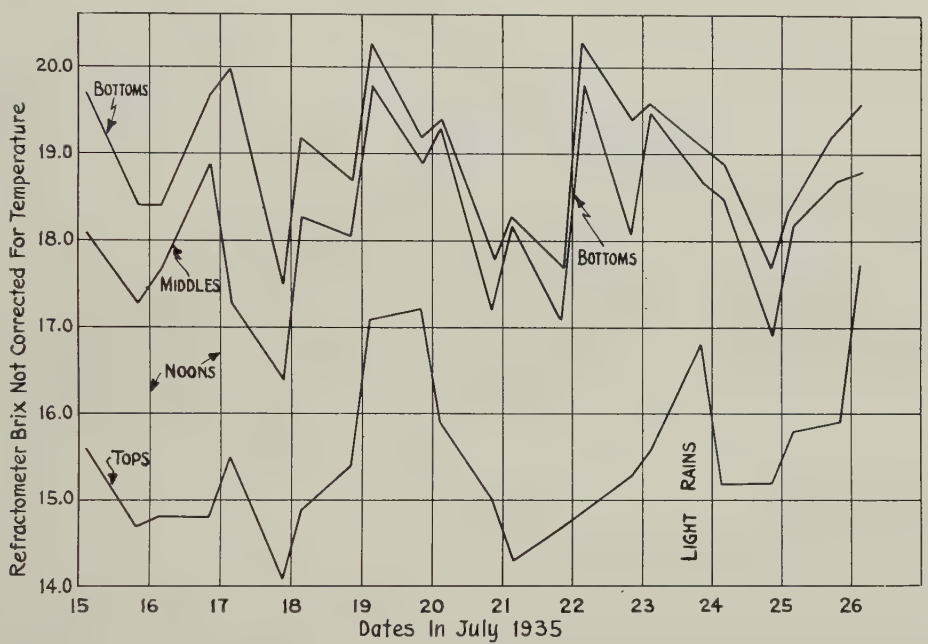


Fig. 1. Diurnal variations of Brix as measured with the hand refractometer. Variety H 109, Pioneer Mill Company, Ltd. Field B-4.

As has been said, each of the Brix figures given in the body of Table I is the average of ten individual random samples. Although this number is too small for convincing statistical attack, the 110 morning observations and 120 afternoon observations permit statistical scrutiny.

If again we assume that there is little or no increase in the soluble sugars present at the three points of observation, during the twelve days in question, we may average the entire number and equip each with some function of its variability. In this case, the old "probable error" is used.

When this is done, we can, within the limits of the correctness of the assumption given above, arrive at some measure of the significance of the differences reported. The results of these computations and the odds by which the significance of the differences may be judged are given in Table II.

TABLE II

Averages, Differences and Odds that the Differences are Significant from Summarized Brix Measurements in Table I

Part Sampled	Brix AM	Brix PM	Difference	Odds that Difference is Significant
Bottoms	18.6±0.11	19.4±0.09	0.8±0.14	7000:1
Middles	17.8±0.15	18.6±0.14	0.8±0.20	142:1
Tops	15.4±0.16	15.8±0.15	0.4±0.22	3.4:1

The odds given in the last column of Table II except in the case of "Tops" may be considered as highly significant. It is again to be noted that the moisture content cycle is most positive in the bottoms, less positive in the middles and least and possibly not significant in the tops of the canes.

It should be noted that the Brix figures purport to give the percentage of total solids in the solution on the refractometer plate. In order to convert the refractive index of the material into terms of Brix, a specific temperature must be selected as a standard and apparent readings must be reduced to this standard if reliable comparisons are desired. Browne's (3) refractometer table is based upon a temperature of 28 degree C.

Since the refractive index of sugar solutions decreases with increasing temperatures, it is apparent that uncorrected observations upon materials at a higher temperature than the standard will result in an apparent sugar percentage which is less than the real value, while observation upon materials at a lower temperature than the standard will give results that are greater than the true value.

Consequently the average Brix values secured in the afternoon must be increased, if we desire to form some basis of comparison since the temperatures in the cane were patently higher than 28 degree C. For similar reasons the morning averages would be reduced. It is evident that the differences reported in Table II are considerably less than the real differences. For obvious reasons, the probable errors for each of the averages would be practically the same after adjustment for temperature and the odds greatly increased.

Observations at the Hilo Variety Station

Similar observations made at the Hilo Variety Station failed to give convincing verification of the findings at Pioneer Mill Company, Ltd. Here both POJ 2878 and Yellow Caledonia were studied in accordance with the procedure already outlined.

The observations covered the period from August 2 to August 10, except for August 4. Both varieties were close to the Variety Station. The Yellow Caledonia was 16½ months old at the time of sampling; the crop was the first ratoon.

As in the case of the studies on Maui, each of the Brix figures reported is the average of ten individual samples. The details of the observations, except for the individual determinations contributing to the daily averages, are given in Tables III and IV.

TABLE III

Hand Refractometer Brix Readings, Morning and Afternoon Observations
Variety: Yellow Caledonia
Hilo Variety Station

Date 1935	Bottoms AM	Bottoms PM	Middles AM	Middles PM	Tops AM	Tops PM
Aug. 2	18.9	19.3	18.7	19.2	19.7	18.3
3	18.6	18.6	19.0	19.9	18.7	17.6
5	18.8	20.1	19.4	18.5	19.3	18.0
6	20.2	19.7	19.9	19.8	19.5	18.9
7	19.5	20.0	19.5	19.3	19.6	19.6
8	19.0	19.4	19.1	19.2	18.5	18.1
9	19.5	18.8	19.5	19.6	17.7	18.4
10	19.8	19.8	19.5	18.9	19.0	17.7
Avg.	19.3	19.5	19.3	19.3	19.0	18.3

TABLE IV

Hand Refractometer Brix Readings, Morning and Afternoon Observations
Variety: POJ 2878
Hilo Variety Station

Date 1935	Bottoms AM	Bottoms PM	Middles AM	Middles PM	Tops AM	Tops PM
Aug. 2	20.8	20.3	21.6	20.9	20.0	20.1
3	19.3	19.1	19.7	20.1	18.1	17.1
5	19.3	20.1	20.7	18.5	16.5	18.0
6	19.5	19.9	20.3	20.1	15.8	20.6
7	19.7	20.3	20.6	20.6	19.9	19.5
8	18.8	19.6	20.0	20.1	16.3	18.8
9	20.1	20.0	20.6	21.2	19.2	20.8
10	20.5	19.7	21.4	20.7	20.8	19.6
Avg.	19.8	19.9	20.6	20.3	18.3	19.3

With neither Yellow Caledonia nor POJ 2878, under conditions as they existed, was there any significant difference between the uncorrected morning and afternoon Brix readings. No observations were made upon temperature at the time of observation. Brown (3) states that in this bracket of concentrations a change of temperature of one degree Centigrade results in a change of Brix of 0.07 per cent. Hence a total difference in temperature between the morning and afternoon reading of 5 degree C. would increase the difference of Brix by 0.35 per cent. As has been indicated, this correction increases the difference between the morning and afternoon samples without modifying the probable error of the difference. Whether this correction would show significant differences in the Brix with these two varieties at Hilo cannot be determined without definite data as to the temperatures involved.

It should be noted that frequent rains may have added their effect to the sequence which might have been expected from the Maui results.

Observations at Waipio, Oahu

More detailed observations at the Waipio Substation tended to strengthen the impression that H 109 at least, when grown under irrigated conditions, seemed to enjoy a diurnal fluctuation of cell sap concentration.

In these series of tests* fifteen individual joints were sampled with the hand punch and flagged in such a way that the same joints might again be sampled as a measure of modifications in the concentration of materials in solution.

This first series consisted of observations on the evening of October 3, 1935, and the morning of October 4. Care was taken to time the periods of observation so that the morning temperatures and afternoon temperatures might be as similar as possible. In addition to the apparent Brix readings for each of the observations, Table V gives the temperature at the time of making each of the Brix determinations.

TABLE V

Hand Refractometer Brix Measurements on Fourteen Selected Joints of H 109 Cane, Age 12 Months, Waipio, Oahu

	Morning October 3		Afternoon October 4	
Joint	Brix	Temperature	Brix	Temperature
1	14.8	23.4°C	15.0	26.6°C
2	17.6	23.6	17.3	26.2
3	14.5	23.8	14.4	25.9
4	16.0	23.6	16.7	25.7
5	13.2	23.6	14.0	25.8
6	17.1	24.6	17.6	25.6
7	15.8	24.6	15.3	25.4
8	16.8	24.7	17.1	24.8
9	16.6	25.0	17.6	25.2
10	15.6	25.0	16.3	25.7
11	13.8	25.0	15.4	25.6
12	12.8	25.0	13.8	25.8
13	14.0	25.0	14.0	25.5
14	14.1	25.0	14.2	25.5
Avg.	15.2	24.4	15.6	25.7

Since the same joints sampled in the morning are sampled again in the afternoon, we have 14 pair of observations which may be compared by Student's method. When this procedure is used, the odds are more than 50:1 that the difference is significant.

In order to guard against the possibility of having the observations of the second series influenced by the punctures in the joints made for the previous series, a second set of observations was planned.

In this case the observations of the first series on the selected joints were made late in the afternoon of October 12, 1935. The second series was run on the following morning. Here the differences were much more marked; again the afternoon readings exhibited a higher Brix than the morning.

Details of observations are given in Table VI.

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* The writer is indebted to Ernest Johnston and Caleb Burns, Jr., students at the University of Hawaii, for assistance in making these observations.

TABLE VI

Hand Refractometer Brix Measurements on Fifteen Selected Joints of H 109 Cane, Age 12 Months, Waipio, Oahu

	Afternoon October 12		Morning October 13	
Joint	Brix	Temperature	Brix	Temperature
1	20.1	24.1°C	15.9	21.8°C
2	14.5	24.2	13.2	21.7
3	15.2	24.2	13.5	21.6
4	13.6	24.1	12.3	21.6
5	13.0	24.1	12.0	21.6
6	15.8	24.2	13.8	21.7
7	16.0	24.3	15.0	21.7
8	15.3	24.2	12.6	22.0
9	9.5	24.1	8.4	22.0
10	18.8	24.1	18.1	21.8
11	17.5	24.0	16.8	21.8
12	11.8	24.5	9.7	22.4
13	15.0	24.4	14.1	23.1
14	16.9	24.3	15.8	23.0
15	15.4	24.3	12.9	22.8
Avg.	15.2	24.2	13.6	22.0

Here the numerical difference between the average afternoon and morning Brix is greater than in the previous series. The odds, again by Student's method, are much more than 100:1 that the difference is significant.

Although some care was given to starting the two runs at such times that the temperatures would be equal during the two runs, this end was not gained. In both cases, the afternoon temperature was greater than in the morning. If this were allowed for and corrections applied as suggested by Browne (3), the differences and consequently the odds would be somewhat increased.

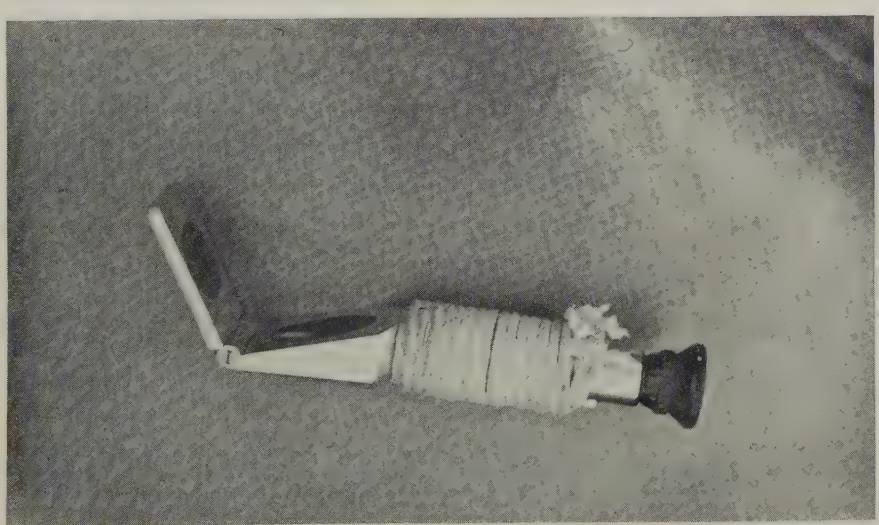

Fig. 2. The hand refractometer insulated with asbestos to protect it from the effect of body temperature.

Every care was used to get results that were accurate within the capacity of the instrument. The plate was flushed with distilled water after every observation and wiped dry with a clean cloth. An insulating sleeve of asbestos yarn was attached to the barrel of the refractometer to protect the device from the body heat of the operator. The device with its insulation is shown in Fig. 2.

Detailed Growth Measurements

Since such fluctuation of moisture content in the stick should logically find some expression in growth response, a series of growth measurements were made at Pioneer Mill Company, Ltd., concurrently with the Brix measurements already noted. The usual procedure was slightly modified.

In the usual procedure with growth studies (10) (11), twenty sticks are permanently selected and daily measurements made upon the distance between a permanent datum and the last visible ligule or "dewlap."

During the present measurements, this procedure was followed except that observations were made twice a day. One series of measurements was made during the early morning and another at about sundown. Moreover, observations on the growth history of the leaf spindle were made twice daily. This was accomplished by establishing a fixed point, by means of India ink on the innermost leaf in the leaf spindle and measuring from this point to the corresponding datum point. Consequently, we have two measures of the growth performance of the twenty sticks under consideration in considerable detail. It should be mentioned that the twenty sticks under measurement were in the middle of the area being sampled for Brix.

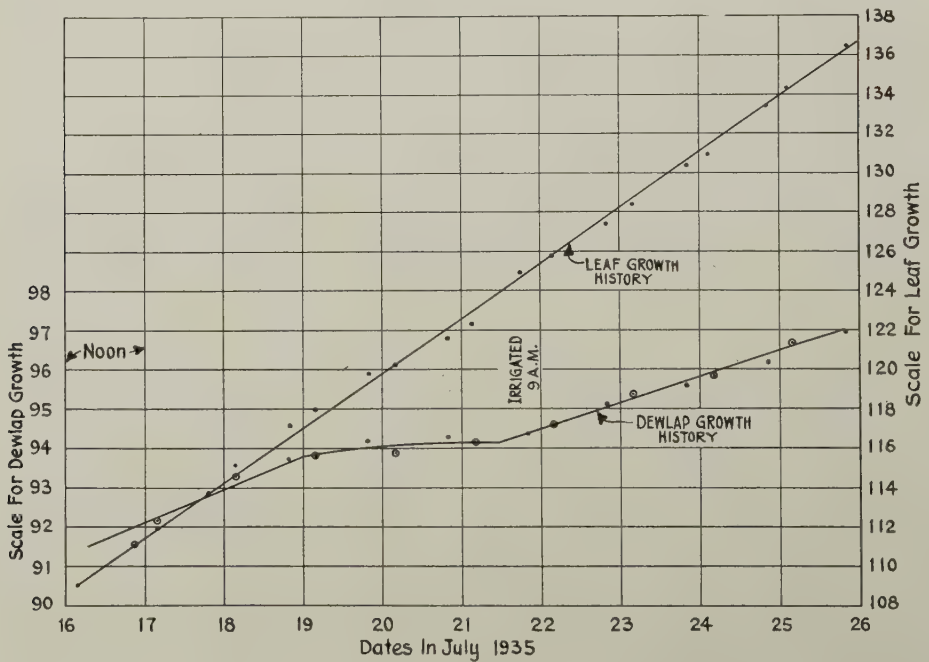

Fig. 3. Results of growth measurements at Pioneer Mill Company, Ltd. Note the typical growth history of the dewlap. Of particular interest is the uniform advance of the leaf bundle after elongation of the stem below the dewlap has ceased.

The details of these average measurements are shown in Fig. 3. The lower curve giving the growth history of the "dewlap" is typical of those reported from Waipio (10) and Waialua (11). Here the growth is at approximately a uniform rate until soil moisture becomes a limiting factor. After a short transition curve, growth is resumed after the irrigation noted.

The addition of a second series of points during each twenty-four-hour period gives some evidence that growth is extremely slow during the daylight hours when soil moisture is low. In fact, on the afternoons of July 20 and 21, there seems to be an actual shrinkage of the tissue. How real this shrinkage is cannot be determined from the evidence at hand. But it seems apparent that the rate of growth is significantly different during the day and night at low moisture contents.

Quite a different picture is presented by the growth history of the leaf bundle: Here the datum point on the leaf seems to move uniformly and quite independently of soil moisture depletion within the limits covered by the Pioneer observations.

Similar observations on the plants growing in small tanks at the Experiment Station in Honolulu show similar results. Here the plants were younger and being grown in containers permitted approximations of the relative soil moisture content by weighing.

The growth and soil moisture histories for Tank No. 1 are shown in Fig. 4. Here the gross weight curve which is a measure of the rate of soil moisture depletion shows its customary form with a weight of 164 pounds being associated with a

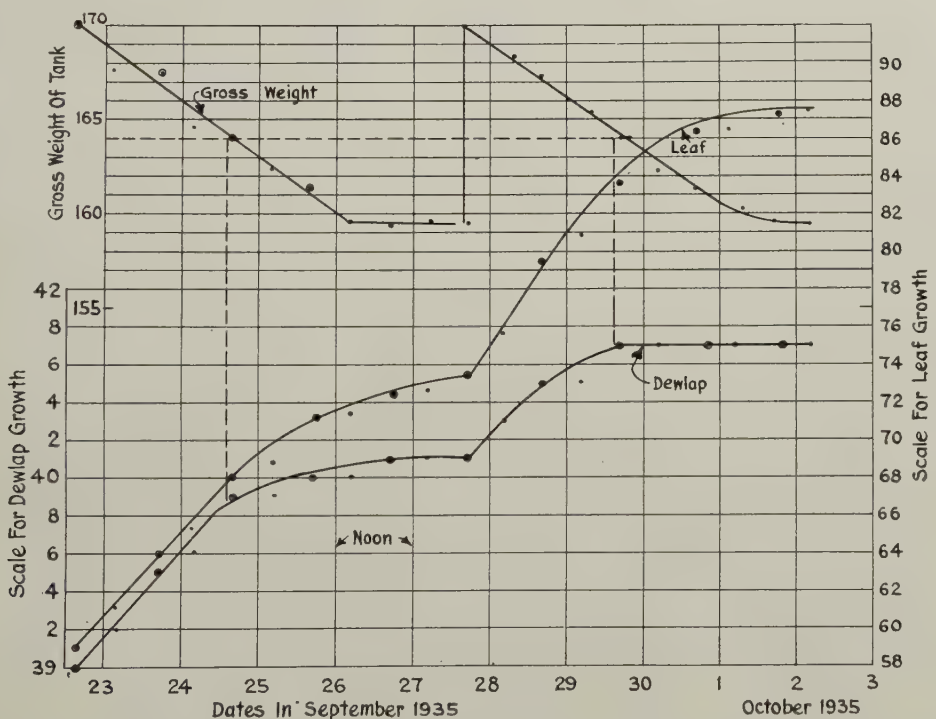

Fig. 4. The growth history of H 109 cane grown in small tanks at the Experiment Station H.S.P.A. Here the leaf bundle continues to elongate for some time after the permanent wilting percentage has been reached.

physiological disturbance which has resulted in a marked reduction of the rate of growth as measured by dewlap measurements. It is to be noted again that the spindle continues to grow for some time but at a reduced rate. Here, too, it is evident that during periods of low soil moisture contents growth as measured by both dewlap and leaf extension is greater by night than by day.

It should be noted that the plants reported in Fig. 4 were seven months old in September; only a short section of millable cane was visible.

Discussion

The suggestion that the cane plant grown in the hot, dry environment of most of the irrigated plantations of Hawaii suffers diurnal variations in moisture content is not without support from workers with other plants. Batholomew (2) reports that the leaves of the lemon tree are often kept turgid at the expense of moisture stored in the fruit. After reporting a long series of observations in detail, Batholomew states, "The records show that during periods of excessive evaporation there may be not only a daily water deficit but one which may last during the night as well as during the day for at least three or four weeks at a time. That such a deficit must have a profound effect upon the fruit would appear to be evident." Although such conditions might adversely affect the quality of the lemon fruit, it is not clear how such deficits might affect the sucrose content of sugar cane.

Livingston and Brown (8), working with desert plants near Tucson, Arizona, report large variations in the moisture content of leaves during a twenty-four-hour period. In these studies a variety of pigweed (*Amaranthus palmeri*) showed a reduction of maximal leaf moisture of 39 per cent during the heat of the day while mesquite (*Prosopis velutina*), the most constant species studied, showed a reduction of 14.3 per cent.

Maximov (9) gives a comprehensive survey of work in this field and adds the following comment, " . . . the suction developed in wilting leaves—provided that the plant wilts sufficiently slowly and deeply—is transmitted to all parts of the plant organism. Under these conditions the transpiring leaves draw upon such reserves of water as the other organs may contain."

Krasnoselsky-Maximov, reported by Maximov (9), is more specific. Mme. Maximov noted diurnal variations in leaf moisture similar to those reported by Livingston and Brown. But she adds that, "These fluctuations naturally vary from day to day. On hot days with high moisture deficit in the air (that is low relative humidity) the fluctuation was more pronounced, while on cooler days they were less perceptible." Attention is again directed toward the relative rate of supply of moisture by the roots and the rate of demand by the atmosphere (15).

More recently new devices developed by Bachmann (1) have permitted the precise measurement of leaf thickness and leaf area during these diurnal variations in leaf moisture. Such measurements show a decided correlation between leaf thickness as well as area, and moisture content.

Recent work by Hartt (7) shows that the same processes are evident with sugar cane. Dr. Hartt determined the moisture contents of leaves, sheathes and green-leaf cane (H 109) after a long period of darkness during which full turgidity was

presumably restored and after five hours of bright sunlight and high temperature. Two series of such tests were run. In one of these, the plants enjoyed abundant soil moisture; in the other, the moisture content was unquestionably below the permanent wilting percentage.

Dr. Hartt's results in a modified form are given in Table VII.

TABLE VII

Moisture Contents of Varying Parts of the Cane Plant After Different Exposures

	Per Cent Moisture Time of Sampling			Per Cent Moisture Time of Sampling	
	8 AM	1 PM		8 AM	1 PM
High Soil Moisture:			Low Soil Moisture:		
Leaves	70.7	69.6	Leaves	67.9	66.6
Sheathes	85.2	84.2	Sheathes	79.6	76.3
Green-Leaf Cane ..	88.5	87.8	Green-Leaf Cane ..	84.4	84.1

The decreases in moisture contents, with exposure to the high evaporating capacity of the greenhouse, are not as great as those which have been noted in the literature. But the modifications of moisture contents are significant in all cases when considered in conjunction with their probable errors as given by Dr. Hartt. Moreover, it should be noted that only five hours elapsed between the two times of sampling. It is highly probable that the reduction of moisture in blades, sheathes and stems would continue in the afternoon, resulting in a diurnal variation much greater than that reported.

It should be noted that evidence of this variation in moisture content in the cane plant has been reported only from areas in which the evaporating powers of the atmosphere during the day are great. Whether or not the efforts to trace such diurnal variations at Hilo failed to give significant results because of an insufficient demand upon the aerial parts of the plant during the day or because of the different varieties in use there cannot be determined from the present data. If the first alternative is involved, the significance of a wide range of temperatures between day and night is apparent, as has been suggested by Das (4).

If it be assumed that, under the hot, dry environments of irrigated plantations in Hawaii, the sugar cane plant suffers a diurnal variation in moisture content, one is tempted to speculate upon the relation of this phenomenon upon sucrose formation.

Considerable basis for such speculation is to be found in the literature. For example, Spoehr (12) demonstrates that, with cactus, a lowering of the moisture content in the plant is associated with an increase in polysaccharides and a reduction in monosaccharides. Das (5) in a thesis presented to the University of Minnesota states that, "if the cells are high in water, the elaborated carbohydrates move toward the complex types, on the other hand when cells are low in hydration the carbohydrates move toward the soluble type and in cane, accumulate as sucrose." And again by correspondence Das (6) states that, "we have evidence that seasonal variations in the sucrose content of even the dry-leaf section are associated with changes in the water content." Hartt (7) has discussed the significance of moisture content

of cells of the sugar cane plant, upon the physiological processes underway on the basis of the conditions required for the chemical processes which might be expected.

It is recognized that other conditions than varying moisture contents are of great importance in the general problems of sucrose formation and storage. Of these the enzymatic equilibrium is perhaps the most important. A discussion of this phase of the problem is outside the scope of the present paper. It may be said, however, that Spoehr (12) discusses the relation between this equilibrium, temperature and moisture content in some detail.

Such experimental results, as those presented, are suggestive rather than conclusive. The need for more evidence is apparent not only toward the end of verifying the tentative results presented but also in the interpretation of such results in the laboratory.

If any credence can be given these results and the speculation based upon them, one is impressed with opinions and practices in the industry which have been based upon observations and field experiments. For example, it used to be said that it did the cane crop good to dry out. At Oahu Sugar Company, Ltd., and at Waianae Company, a practice of "tapering off" the irrigation interval prior to harvest has resulted in high sugar yields although such a practice should not, from our present conceptions, increase cane tonnage. Moreover, the old determinations of optimum irrigation intervals resulted in the use of intervals from three to eight days longer than those determined by cane growth studies.

The statement has frequently been made that the inner leaf bundle of sugar cane rarely shows signs of wilt early in the morning regardless of soil moisture. It seems possible, at least, that the moisture required for this restored turgor may be translocated from other parts of the plant as Maximov (9) has suggested.

Summary

Some evidence is present that the moisture content of H 109 cane, grown under irrigated conditions, suffers a diurnal variation of considerable magnitude. Such moisture content is higher at daybreak and lower at nightfall.

Such determinations were made by use of the hand refractometer, it being assumed that variations in Brix might be more accurately charged to variations in moisture than in soluble material.

An attempt to duplicate the results with other varieties (POJ 2878 and Yellow Caledonia) at Hilo Variety Station failed to give significant results unless an unconvincing temperature correction is invoked.

There is some speculation as to the role of this daily moisture fluctuation and sugar formation.

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The Effect of Nitrogen on Cane Yield and Juice Quality*

By U. K. Das and A. H. Cornelison

In the course of the last fifteen or twenty years most of the sugar plantations of these Islands have substantially increased, and some have actually doubled, their per acre yields of sugar. Various factors have contributed; important among these is the increased use of nitrogen. During the same period, however, the quality of juice has steadily gone down—the decline amounting in some cases to nearly fifteen per cent. Some of us with a bias for figures have calculated that if we had the present tonnage of cane together with the old time quality, the sugar production per acre, and hence our margin of profit, would be considerably greater. An attractive prospect indeed, marred only by the solemn warning of the sceptic that we may not eat our cake and have it too, or something to that effect. However, the proposition seemed so attractive that we felt it would be worth while to inquire if quality of cane and quantity were by nature opposed to each other; that is, if it would not be possible to have the increased tonnage without losing so much of the quality.

The problem we set out to answer in this preliminary experiment was, "How does nitrogen affect yield and quality of cane?" Surely without such knowledge all our efforts to improve quality will be like shooting at a target in the dark. We may hit it but the chances are greater that we shall miss it.

We felt that one satisfactory way to approach the problem would be to study the effects on yields and quality of three different amounts of nitrogen applications—a low application such as was used a decade or so ago, a medium or standard application such as is used at present on the irrigated fields of Oahu, and a very high application such as our past experience indicates to be entirely too much. Actually the amounts we used for this study were 133, 266, and 645 pounds per acre respectively. The nitrogen was applied in seven doses, the last dose going in on the fourteenth month. In each series we applied the same amount of phosphate and potash fertilizers, the same amount of water and a sufficient quantity of it, so that the differences in yield or quality of cane would be due to amounts of nitrogen alone.

The cane was H 109 planted in three blocks—one each for the low, the medium, and the high series. Beginning at four months and every two months thereafter we harvested one line of cane from each block, took careful weights, crushed the juice and determined sucrose and glucose. We also made many other chemical determinations. There were two good reasons for harvesting the cane at different ages, one was to find out if the differences due to treatment lasted through the entire life of the crop, or disappeared as soon as we stopped fertilization, and the second was to see if the treatment differences were repeated from harvest to harvest. In the following pages, we are reporting the results of eleven such harvests—the last one being at the age of 24 months.

Only too often we find it difficult to compare one series of planting with another because the original stand was different. To eliminate this difficulty we planted a

* A more technical account is to appear in the April 1936 number of Plant Physiology.

very large number of seed pieces and after germination kept the same number of mother stalks (i.e., stalks that arose directly from the seed piece) in each line in the three treatments. This number was 65 for the 25-foot lines used or 2.6 stalks per running foot. Our past experience had indicated that probably that was all that H 109 cane could carry per foot. (Here we might mention that the results of this experiment show that as many as 3.2 stalks of H 109 can be grown on one foot of line.) Furthermore, we were interested in studying how many daughter stalks and grand-daughter stalks (suckers) would come up, so we tagged all these mother stalks in order that at no time we would have trouble in identifying these canes in the field.

Color, Width, Length and Longevity of Leaves (Fig. 1)

We found that as the nitrogen application was increased, the color of the leaves became darker green to almost blue-green. In the low treatment the leaves appeared pale and yellowish. The difference in color was more marked around ten to twelve months. After the nitrogen application stopped, the color differences slowly began to disappear.

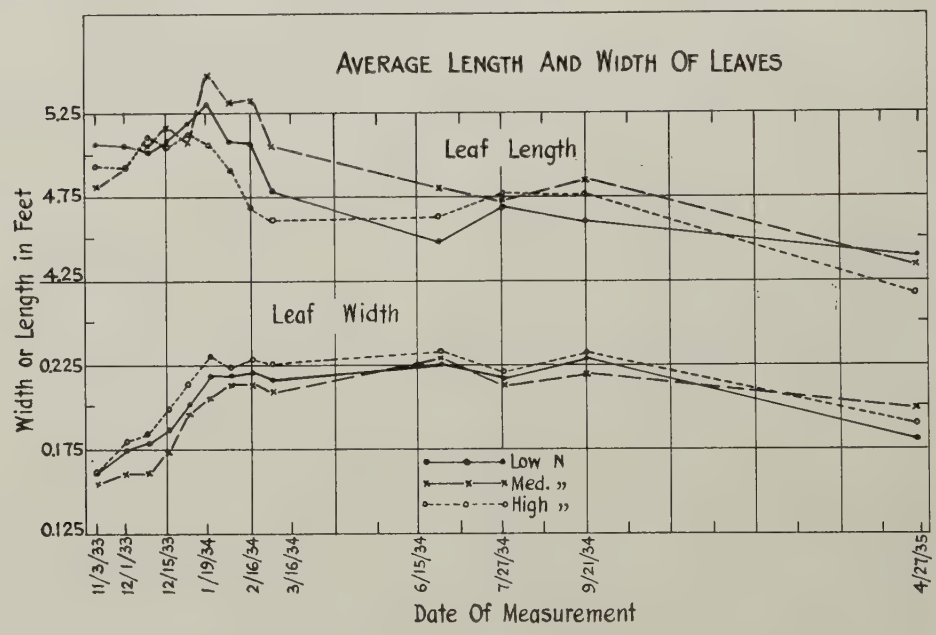

Fig. 1

In general, the higher the amount of nitrogen the wider are the leaves, although the same thing cannot be said with certainty of the length of leaves. Interestingly enough, the leaves formed at the "boom stage" were wider and larger than those formed at any other time. After the application of nitrogen stopped, the leaves began to be narrower and shorter, like those of cane growing on poor soil areas.

We found that generally a leaf remains green for about 2 to 2½ months from the time it opens out fully. In other words that which is young, hardly millable top today becomes a part of the dry-leaf cane in about two months.

The higher the amount of nitrogen applied, the greater the number of leaves formed in an interval of time. In our high series we had 41 new leaves per stalk between November 1934, and October 1935, and 37 in the low series in the same period of time, giving us a difference of about 11 per cent in favor of the high series. We know that each leaf is carried on a separate joint, so we conclude that the more nitrogen applied the greater the number of joints of cane formed.

Stand of Cane

Another striking difference was in the matter of stand. The canes in the high series started lodging as early as six months, those in the medium at about eight to nine months, while many of the stalks in the low series were still erect around fourteen to fifteen months. People working with cereal crops have found that early lodging is often due to poor development of roots and of the woody supporting tissue. We believe that such is very likely the case even with sugar cane.

Length Growth (Fig. 2)

To determine if the differences in treatment showed in the rate of length increase, we selected twenty mother stalks from an inside line and measured their length at two-week intervals. From these measurements we calculated the rate of increase in length. For the first few months there was not much difference in this respect between the cane in the three series. However, from about the seventh month on, the differences began to be quite marked—the more nitrogen the greater the elongation. Rather significantly, there was a great difference between the low

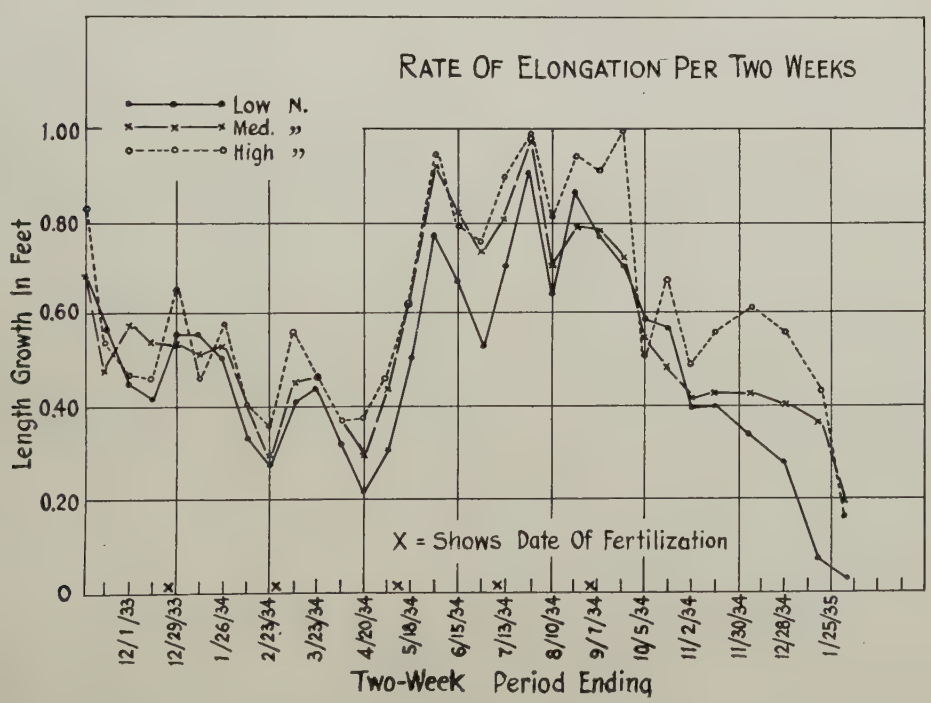

Fig. 2

and the medium series, but only a very small difference between the medium and the high although the amount of nitrogen applied was nearly twice as much in the latter as in the former series. This would show that by going very much beyond our standard practice we may use a lot of fertilizer, but we are likely to get very little extra growth (and tonnage, as we shall see presently).

From time to time we have stated that cane growth and temperature show a close correlation. This study further proves that point. We find that as long as cane is receiving plenty of plant food and water, rate of elongation is directly proportional to our day-degree (which we have defined in the past as degrees Fahrenheit of mean maximum temperature above 70 degrees F.) In other words, we find that if 75 degrees F. of mean maximum temperature for two weeks gives an increase in length of say one foot, then 80 degrees F. for the same length of time increases the cane length by two feet, because our total day-degrees are as 5 is to 10, i.e., as 1 is to 2.

Suckers—Daughter Stalks and Others (Fig. 3)

Not only did we tag the mother canes but we also tagged all the suckers that came up within the first three months. We shall call these suckers the daughter stalks. At harvest the mother, the daughter, and all the other stalks were separately weighed. If we now take the weight of all the cane in the line as 100, we find in our experiment that the mother stalks weighed about 80, the daughter stalks 15 or more. This goes to show that up to the time of our last harvest at 24 months, the late suckers were not of much account. Probably such would not be the case under a different set of conditions or with another variety.

We further found that the more nitrogen applied the more numerous were the daughter stalks and other suckers.

Mortality of Cane (Fig. 3)

From about the sixteenth month on, we found at each harvest that a certain number of the mother stalks had dead or dying tops. This was more noticeable in the high-N series than in the medium or the low. This greater top mortality may be due to the greater crowding, and greater plant competition in the high-N plot than in the others. In the high series we found heavy borer damage; this also might have had something to do with greater mortality. (Our entomologists tell us that the extremely heavy trash blanket in the high series made it difficult for the borer parasites to get to the borer larvae to parasitize them.) At the rate the mortality was mounting, it looked as if we would have no live mother stalks at the end of thirty months or more.

Yield of Cane (Fig. 4)

We have already mentioned that we had one harvest every two months from the fourth month on. Each time we separated the non-millable top from the millable cane. We then cut the millable cane into two parts: (1) the dry-leaf cane, i.e., the part of the cane where the joints are fully exposed and the leaves are either dried up or have fallen off, (2) the millable green-leaf cane where a few wholly or partly green leaves are still attached. The dry-leaf cane is what we usually term the ripe

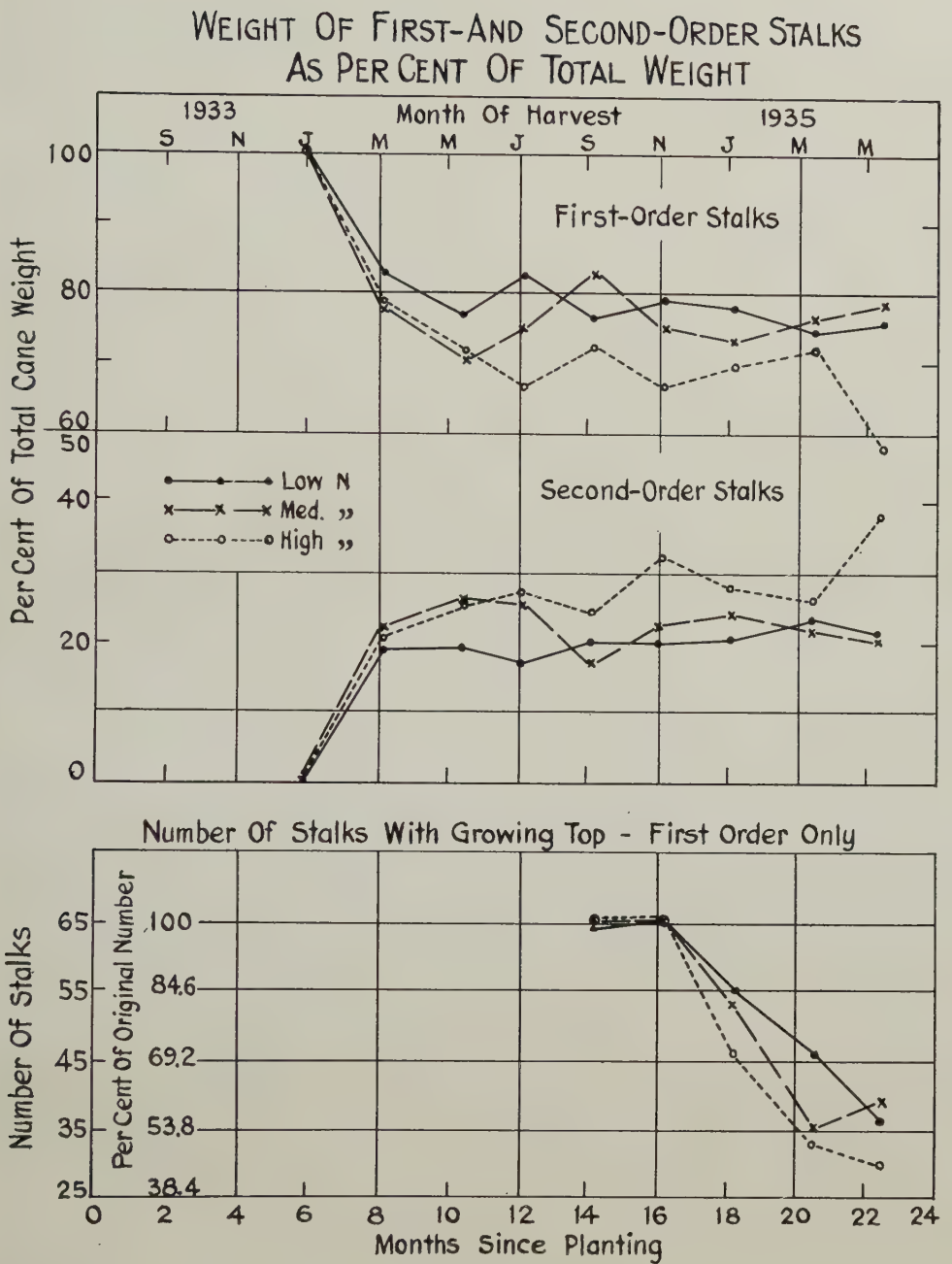
WEIGHT OF FIRST-AND SECOND-ORDER STALKS
AS PER CENT OF TOTAL WEIGHT
1933
Month Of Harvest
1935
S N J M M J S N J M M
100
80
60
50
40
20
0
Per Cent Of Total Cane Weight
First-Order Stalks
Second-Order Stalks
Low N
Med. „
High „
Number Of Stalks With Growing Top - First Order Only
Number Of Stalks
Per Cent Of Original Number
65
55
45
35
25
100
84.6
69.2
53.8
38.4
0 2 4 6 8 10 12 14 16 18 20 22 24
Months Since Planting

Fig. 3

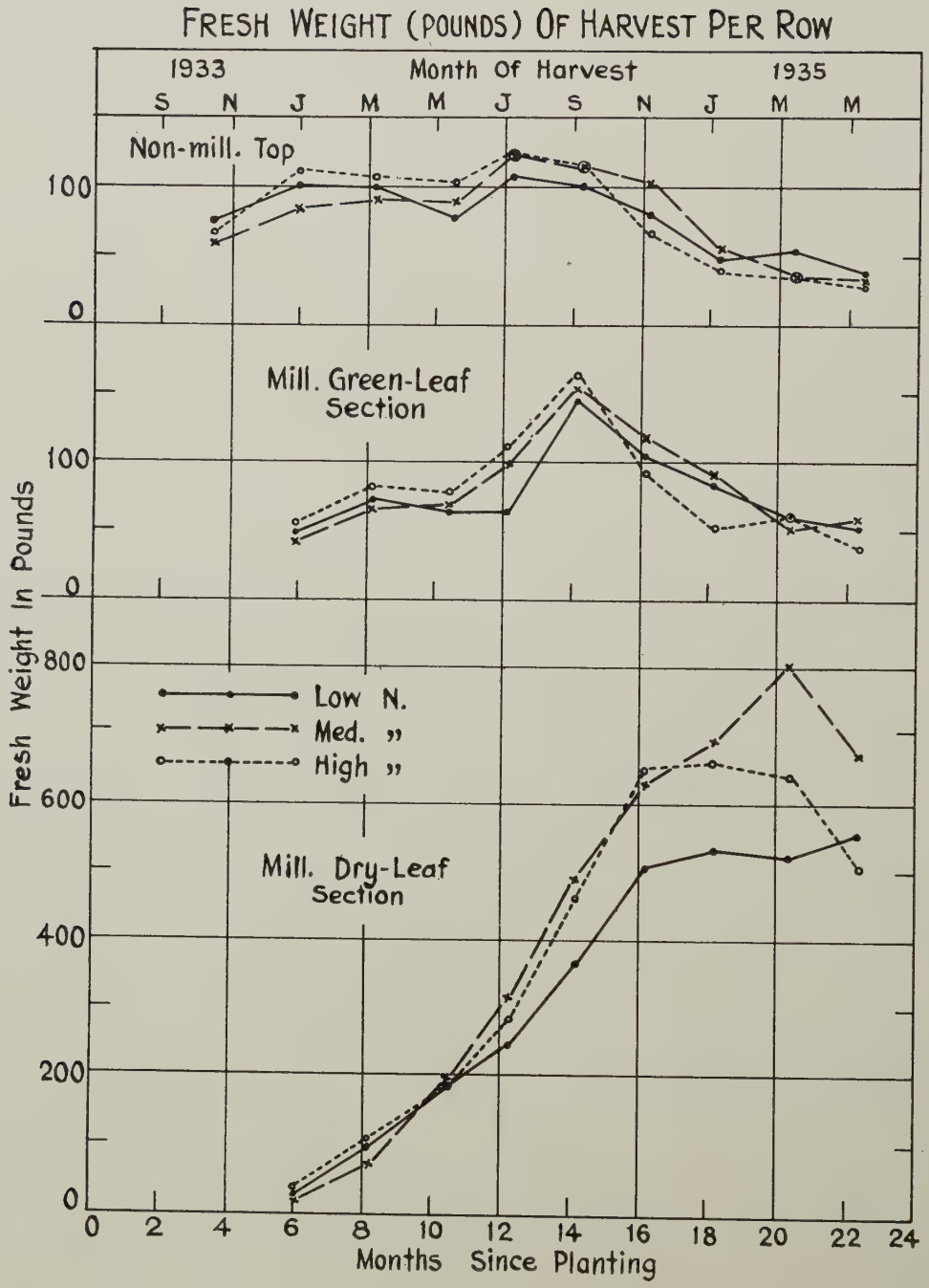
FRESH WEIGHT (POUNDS) OF HARVEST PER ROW
1933
Month Of Harvest
1935
S N J M M J S N J M M
Non-mill. Top
100
0
Mill. Green-Leaf Section
100
0
Fresh Weight In Pounds
800
600
400
200
0
Low N.
Med. ,,
High ,,
Mill. Dry-Leaf Section
0 2 4 6 8 10 12 14 16 18 20 22 24
Months Since Planting

Fig. 4

part of the cane while the green-leaf part is where the juice is not quite as good as it might be.

We found that the more nitrogen applied the more was the weights of the tops, the millable green-leaf and the dry-leaf sections. However, the picture changed a little beginning at the sixteenth month because of great mortality in the high series. It might appear as if in this series we had really given the cane more than was good for it. As a result, in the latter months the medium series showed the highest yield, indicating that our standard practice was probably about right—certainly better than the two extremes of fertilization here given.

That which is the leafy top today becomes a part of the millable stalk in two months and that which is the green-leaf section becomes a part of the dry-leaf section. Therefore the top and the green-leaf sections in the succeeding harvests represent new material. The dry-leaf section on the other hand shows an accumulative effect, for it contains old growth as well as new additions.

We found that for a while the weight of the dry-leaf cane was about the same in all the three series. Then, the low series began to fall behind and stopped growing entirely almost immediately after the nitrogen application was stopped, indicating that the cane in this series was really living, one might say, a hand-to-mouth existence. Surprisingly enough the medium series proved to be decidedly better than the high, especially so in the latter months after mortality started in the high series.

However, when we added the weight of all kinds of stalks including the daughters and the later suckers, we found (Fig. 5) that the high series was slightly better than the medium in cane tonnage up to about the sixteenth month, although this difference was not at all in proportion to the difference in the amount of fertilizer applied. We note with interest that we could very well have predicted this result from our growth measurements. There too, it will be recalled, we found little difference between the medium and the high series.

Summarizing the yield data we may then say that increasing the nitrogen application beyond a certain optimum point will not increase the yield to any extent; in fact, it might even lower the yield by injuring the cane.

Juice Quality

When we speak of juice quality becoming poorer as a result of heavy nitrogen fertilization, we usually have in mind the concentration of sucrose in juice. This concentration is actually the result of two things—the amount of sucrose present and the amount of water present. Thus we may have the same amount of sucrose in two containers—say, two plants—but if the amount of water is different in the two, the concentration of sucrose will be different. Again, we may have actually more sucrose in one plant than in the other but due to greater water content, the concentration might still be less in the first than in the second. We can thus easily see that it is not always safe to think in terms of concentration, if what we are after is the amount of sugar. (True, the greater the dilution of sucrose the greater the cost of manufacture—but we shall not consider the question of cost for the present.) The question then, we asked ourselves, is this, "Does the observed difference between the poorly and the highly fertilized plants merely indicate concentration dif-

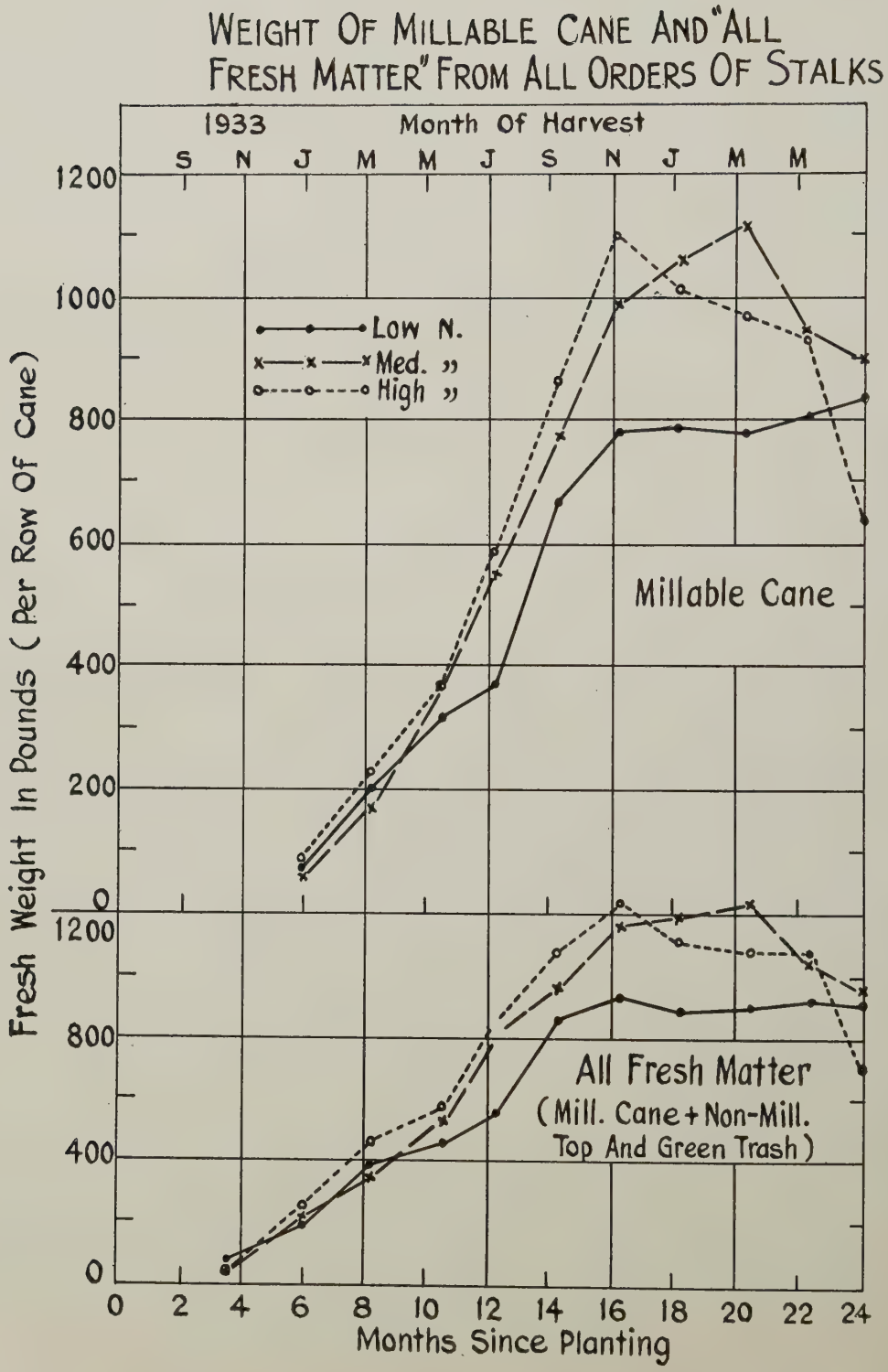
WEIGHT OF MILLABLE CANE AND "ALL FRESH MATTER" FROM ALL ORDERS OF STALKS
1933
Month Of Harvest
S N J M M J S N J M M
Low N.
Med. "
High "
Millable Cane
All Fresh Matter
(Mill. Cane + Non-Mill. Top And Green Trash)
Fresh Weight In Pounds (Per Row Of Cane)
0 200 400 600 800 1000 1200
0 400 800 1200
0 2 4 6 8 10 12 14 16 18 20 22 24
Months Since Planting

Fig. 5

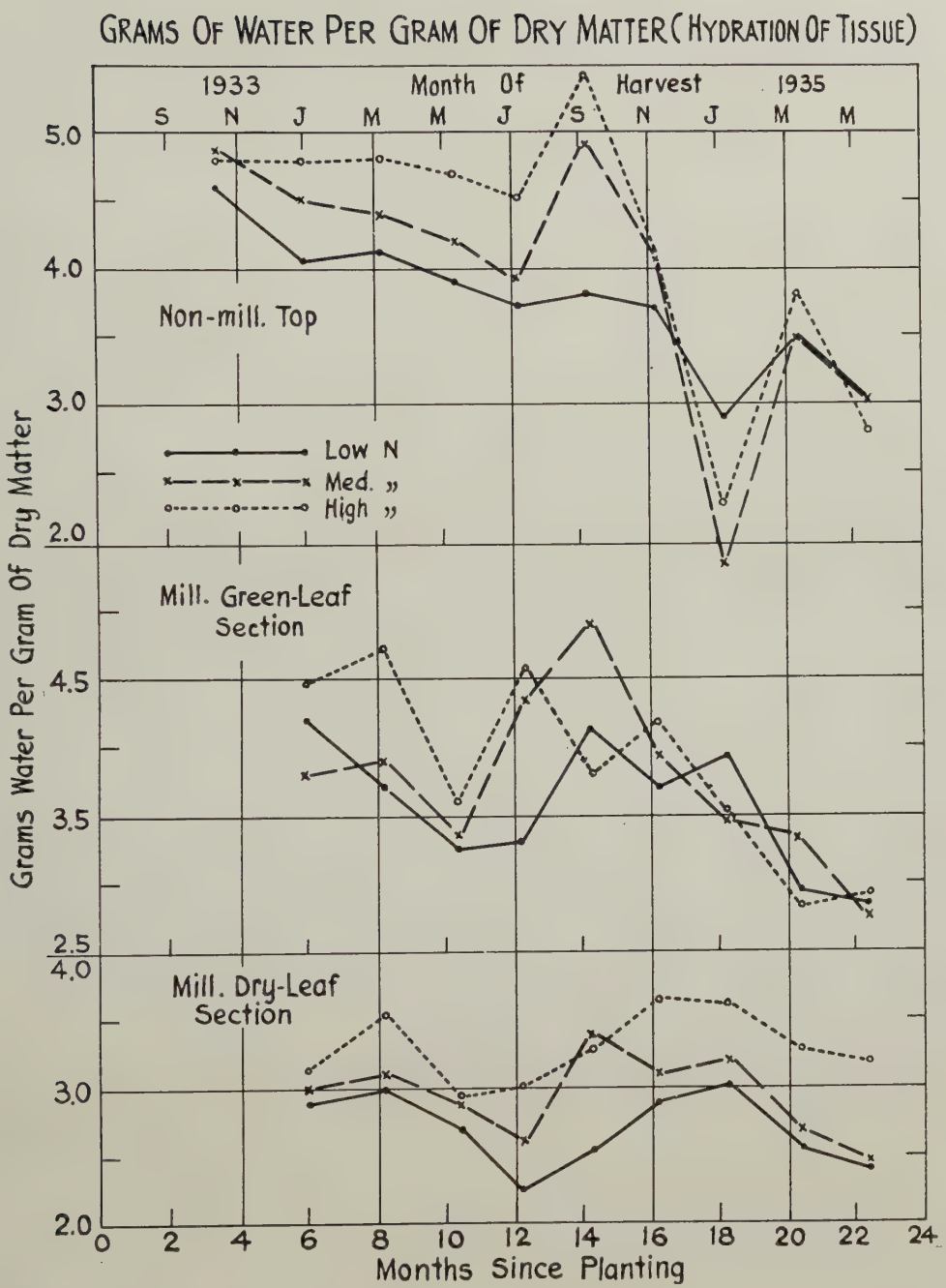
GRAMS OF WATER PER GRAM OF DRY MATTER (HYDRATION OF TISSUE)
1933
Month Of Harvest
1935
S N J M M J S N J M M
Non-mill. Top
Low N
Med. „
High „
Mill. Green-Leaf Section
Mill. Dry-Leaf Section
Grams Water Per Gram Of Dry Matter
5.0
4.0
3.0
2.0
4.5
3.5
2.5
4.0
3.0
2.0
0 2 4 6 8 10 12 14 16 18 20 22 24
Months Since Planting

Fig. 6

ferences due to differences in water content, or are there actually less amounts of sugar in the highly fertilized plants even after eliminating water?" The first thing, then, we had to find out was, "Is there any more water in the high or the medium series than in the low?"

Water Content of Plants (Fig. 6)

No doubt most of us have observed that well-fertilized plants look more succulent than the poorly fertilized ones. In other words, from common observation we might say that there will be more water in the plants receiving more nitrogen. Such is actually the case. From our data on the grams of water per each gram of dry matter (or pounds of water per pound of dry matter) in the plants of the three series, it is quite clear that as long as fertilization was continued, that is, up to the fourteenth month, the amount of water was always greater, the greater the amount of nitrogen applied. It is extremely significant that this holds not only for the leafy top but also for the millable green-leaf and the millable dry-leaf sections. After the stopping of fertilization, all three treatments become more or less alike in the recently grown top and the millable green-leaf sections but the differences accumulated in the past growth still continued to show in the dry-leaf section.

If we study the data a little more we discover that whereas in the young cane the top and the green-leaf parts were much more succulent than the dry-leaf, there was little or no difference between the various sections in eighteen or twenty month-old cane (i.e., months after the last dose of N was applied). We further discovered that while maintaining their respective differences in succulence, all the series showed very marked seasonal influences. For the dry-leaf sections, we find that the water content was the least in April, May, and June and that it reached the maximum around November and December.

There is considerable speculation but little agreement as to the cause of this difference in water content. We shall not discuss here the various arguments put forth but, instead, we shall just mention that both the treatment and the seasonal differences appear to be markedly correlated in our case with the amount of salts (potassium salts, phosphate salts, etc.) in the juice. This has led us to make the suggestion that the greater amount of salts present might actually be the cause of greater succulence. We hope to be able to find something more definite about this in our future studies.

Sucrose Content (Fig. 7)

We studied the sucrose content of cane in two ways: (1) by crushing the entire lot of cane through a "Cuba" mill and analyzing the juice, (2) by determining the sucrose in samples of cane tissue from which all water had been removed by heating in an oven. We found differences in sucrose not only between parts of plants but also between treatments and between seasons. The treatment differences were what we might have expected—namely, lower sucrose content from higher fertilization. However, even more striking were the seasonal differences—the best juice being obtained around May and June, and the poorest around November.

Seeing that we found differences in water content, we would be justified, if we did not examine the data very carefully, to draw the conclusion that differences in

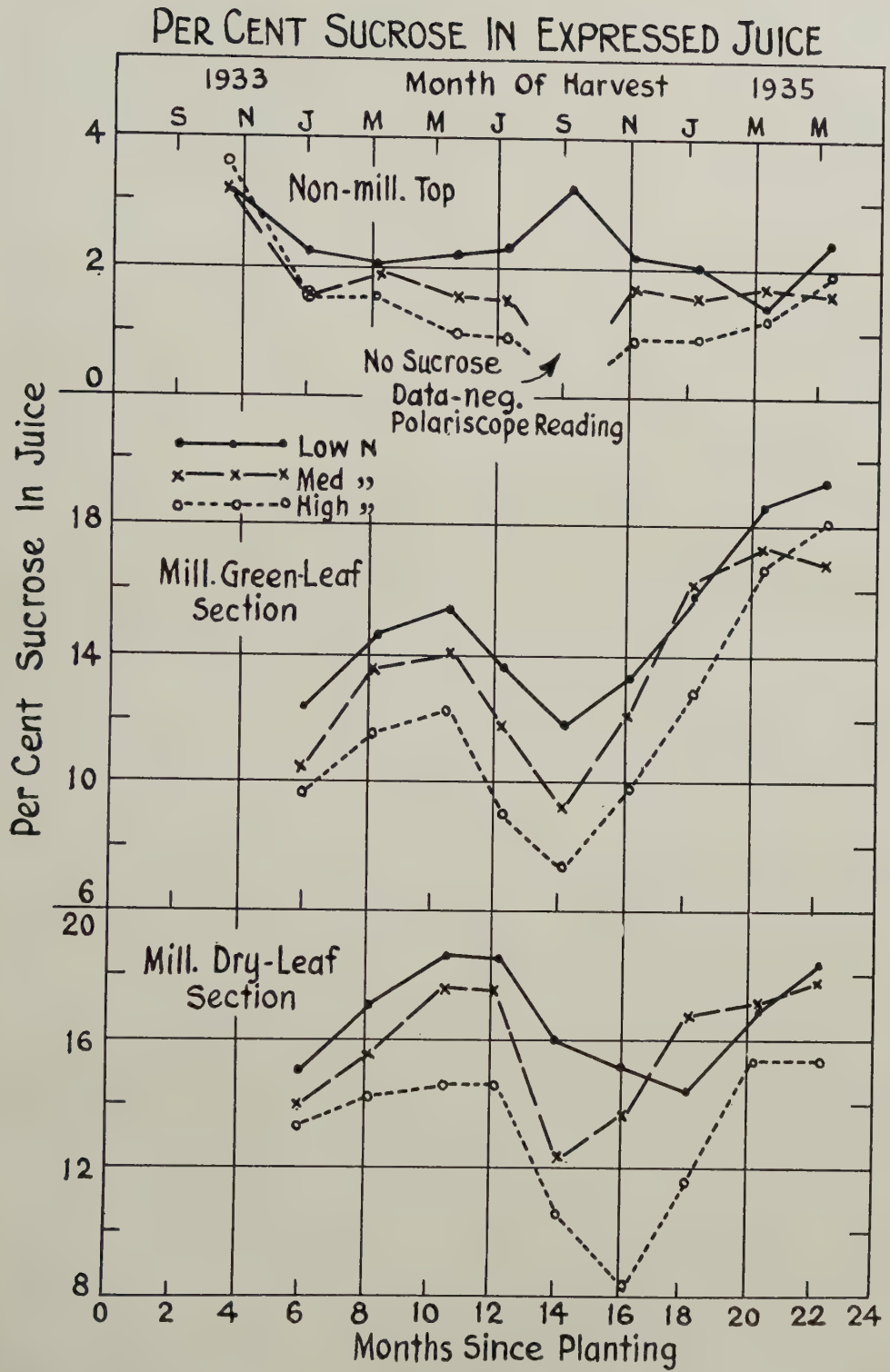
PER CENT SUCROSE IN EXPRESSED JUICE
1933
Month Of Harvest
1935
S N J M M J S N J M M
Non-mill. Top
No Sucrose
Data-neg.
Polariscope Reading
Low N
Med "
High "
Mill. Green-Leaf
Section
Mill. Dry-Leaf
Section
Per Cent Sucrose In Juice
Months Since Planting
0 2 4 6 8 10 12 14 16 18 20 22 24
4 2 0
18 14 10 6
20 16 12 8

Fig. 7

sucrose content in the three series were purely the dilutive effect of water. In fact a strict mathematical analysis shows this to be largely the case. We say largely because on closer examination we find that the differences in sucrose content were too great to be explained by the differences in water content alone. In fact we found that the amount of sucrose per pound of water-free tissue was also less with increasing nitrogen fertilization. We are then led to the conclusion that as we apply more nitrogen the juice becomes poorer because of two reasons: first, the greater amount of water in the plant has a big diluting effect, and second, for some reason, there is actually less sucrose stored. We may now ask, "What may that reason be?"

If there is less sucrose stored, is there anything that is stored in greater abundance in the high than in the low series? On detailed examination of our other data we discovered such to be the case. As we applied more nitrogen we got more glucose in the plants. Furthermore, there appeared to be a clear case of antagonism between glucose and sucrose. When one is high the other is low and vice versa. Even more significant is the fact that if we added glucose and sucrose together then the sum total of these sugars was about the same in the three series in the water-free plant tissue. In other words, the plants in the high series were not necessarily less capable of making sugars but they were inclined to store the sugars manufactured by the leaves in the form of glucose rather than in the form of sucrose. If we were producing both glucose and sucrose in our factories, then we would have little complaint about the poor quality of juice as a result of heavy fertilization.

Various theories may be brought forward to explain the above results. However, we incline to the view that the different water content of the three series might be the actual factor involved. As we picture it, when the amount of water per pound of cane tissue is high, then a relatively large proportion of the sugars made by the leaves will be stored as glucose. Thus in the summer months when the plant normally has a large amount of water and is growing rapidly, glucose will be found in abundance in the juice. In the winter months, on the other hand, the water content of the plant is low and so is the glucose content, while the amount of sucrose is high. If we follow along the same line of reasoning, we should further find that as the young joints which at first contain a large amount of glucose become mature and lose a part of their water, there should be an increase in the sucrose at the expense of glucose. It will be readily seen that the simple conception that we have put forward is in harmony with many of our observations and cultural practices. Let us compare, for instance, the quality of the millable green-leaf and the dry-leaf sections. The former has less sucrose but more glucose than the latter but the sum total of these two sugars is practically the same in both the sections. We would, therefore, be justified in thinking that in passing to the dry-leaf section the green-leaf section lost some of its water and as a result some of the glucose had been converted into sucrose—the total of the sugars remaining the same. Take again the practice on irrigated plantations, of "drying off" before harvest; we would expect, if our theory were right, to find not only an increase in the concentration of sucrose as a result of loss of water from the cane but in addition we should find some change of glucose into sucrose.

We should remind our readers at this point that the conceptions here advanced though partly grounded on experimental evidence of workers abroad, are still far

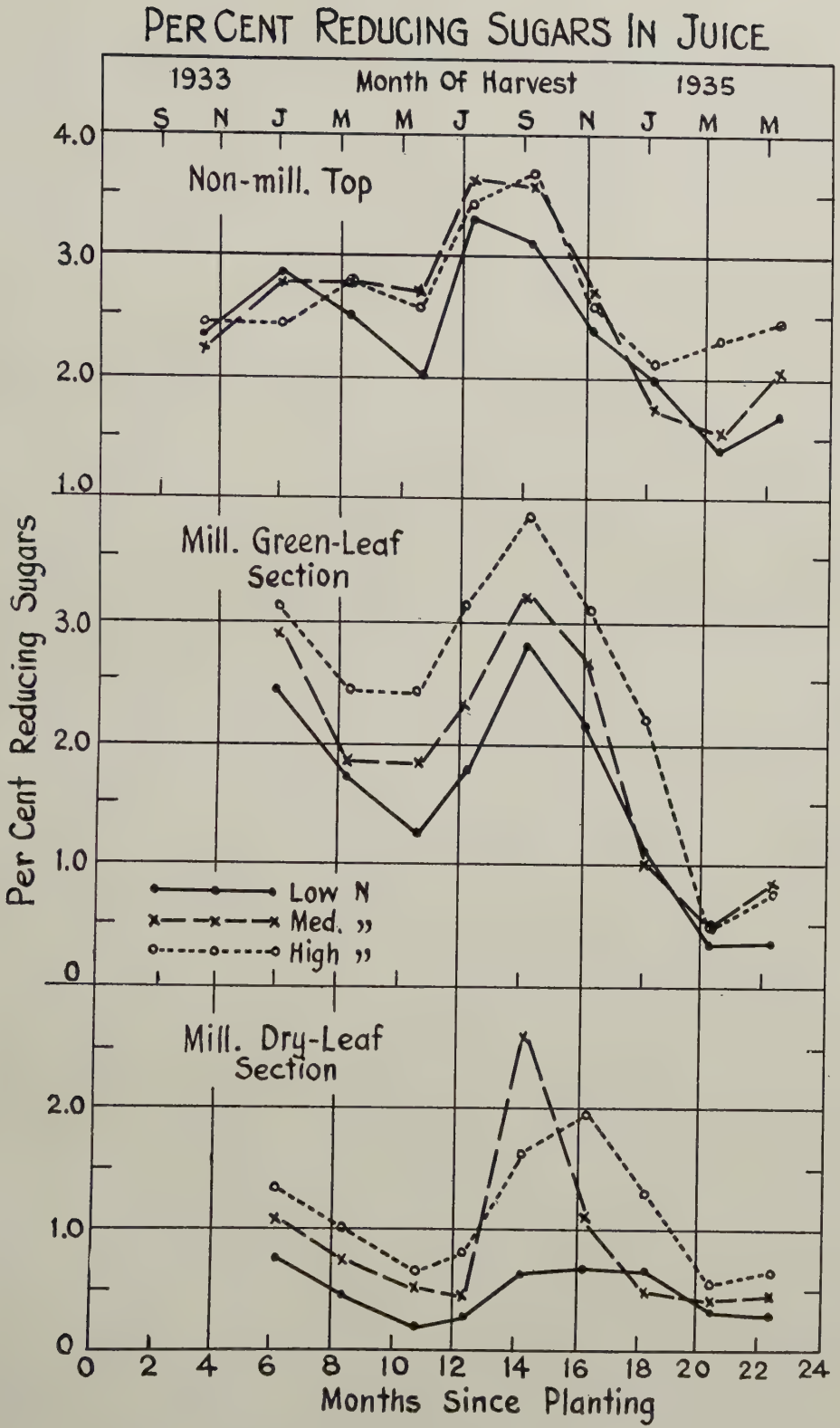
PER CENT REDUCING SUGARS IN JUICE
1933
Month Of Harvest
1935
S N J M M J S N J M M
Non-mill. Top
Mill. Green-Leaf Section
Mill. Dry-Leaf Section
Low N
Med. „
High „
Per Cent Reducing Sugars
Months Since Planting
4.0
3.0
2.0
1.0
0
0 2 4 6 8 10 12 14 16 18 20 22 24

Fig. 8

from being entirely confirmed. We have planned future experiments from which we hope to learn more about the rôle of water in the cane plant.

Before leaving this topic, we should make it clear that if the water content of the tissue is the governing factor then anything that influences this will also influence the sucrose content. Thus cutting off the nitrogen supply, cool weather, cutting off the irrigation—all will have a similar effect on cane juice because all will decrease the water content.

Glucose (Fig. 8)

As we have pointed out in the last topic, glucose and sucrose seemed to be opposed to each other. The high-N series had the lowest concentration of sucrose but the highest of glucose. In the months of April to June, the juice of all series had generally the maximum concentration of sucrose but the minimum concentration of glucose. Of even greater interest is the general similarity between the glucose curves and the cane growth curves. We note that the period of maximum elongation (around September 1934) coincided with the period of maximum glucose, and the period of minimum elongation (around May) with that of minimum glucose. Similar relationship is also observed between the glucose content and the seasonal variations in the water content of the tissue. There is no doubt that these facts are at the bottom of our plantation practice of considering glucose content of juice as an index of maturity.

When we study the glucose curves we must take note of the fact that soon after our nitrogen fertilization was stopped, the glucose content of the recently developed cane, i.e., the millable green-leaf section, began to decrease steadily in all the series and simultaneously the water content also decreased while the content of sucrose went up. This is in agreement with our observations that in the old cane, which has received no fertilization for months, there is little difference between the quality of the dry-leaf and the green-leaf sections.

Other substances of the basic nature of the sugars:

We have also determined other substances that are chemically related to the sugars like glucose and sucrose but are of far greater complexity. Our purpose in so doing was to find out if the reasons for low sucrose content in the high-N series as compared with the low-N series were not partly due to the fact that in the high series there were relatively more of those complex substances. We have found no clear cut evidence yet that there is any such difference. This inquiry also will be pursued in more detail in our future work.

Nitrogen Content of Cane

Since we were applying such varied amounts of nitrogen, we felt it would be of interest to know how much of it was being taken up by the plants in the three series. We have heard a great deal about luxury consumption in plants whereby they take up plant food regardless of immediate needs; this experiment should, then, be a good place to test this theory.

We report the results in two ways: (1) as the amount of nitrogen in each hundred grams of the water-free cane tissue and (2) as the amount of soluble nitrogen

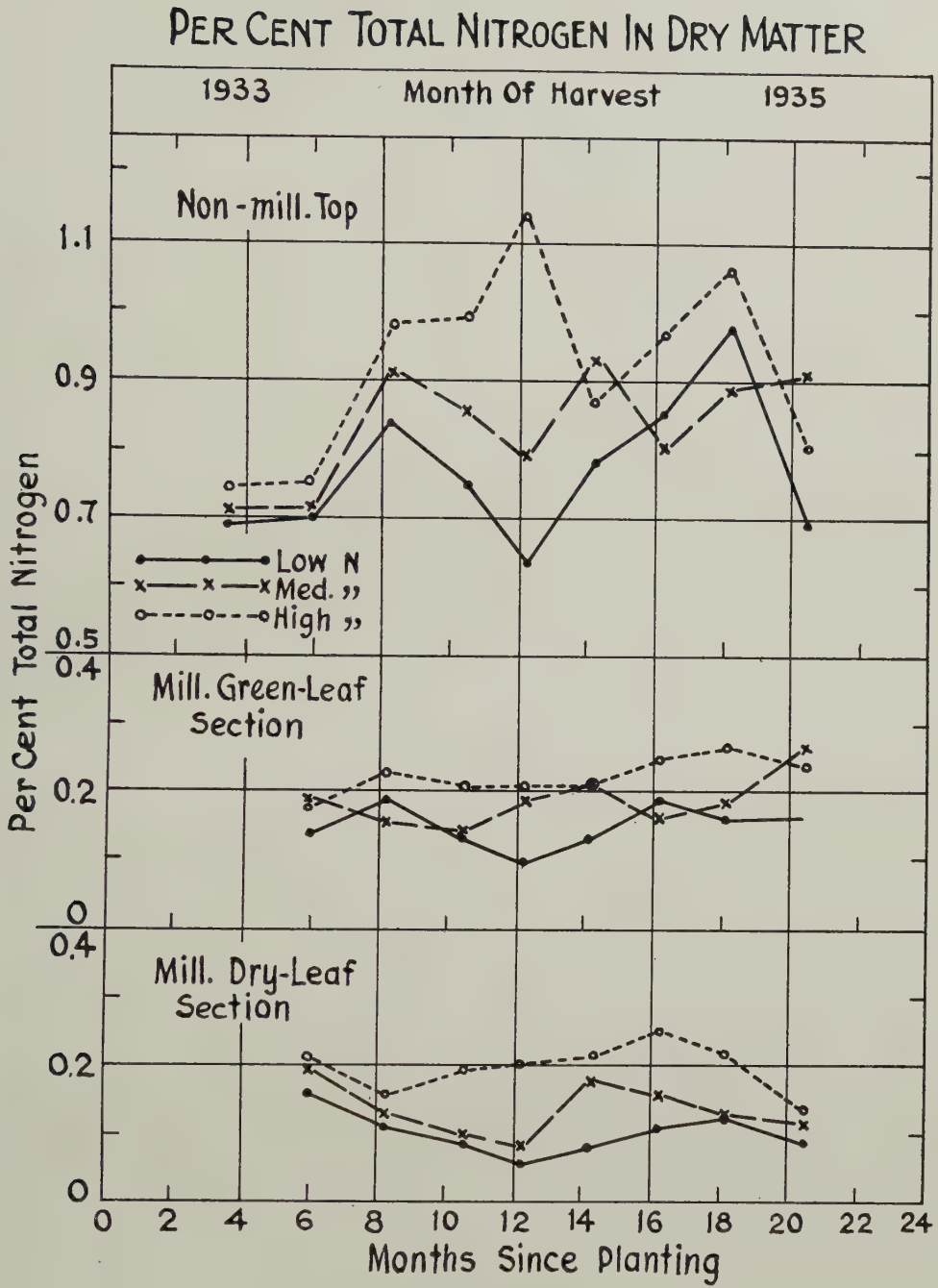
PER CENT TOTAL NITROGEN IN DRY MATTER
1933
Month Of Harvest
1935
Non-mill. Top
Low N
Med. "
High "
Mill. Green-Leaf Section
Mill. Dry-Leaf Section
Per Cent Total Nitrogen
1.1
0.9
0.7
0.5
0.4
0.2
0
0.4
0.2
0
0 2 4 6 8 10 12 14 16 18 20 22 24
Months Since Planting

Fig. 9

in the same amount of dried tissue. The reason for the latter determination is that only a small part of all the nitrogen found in the cane plants is in a soluble form. From the chemical point of view we should expect that the soluble fraction will really be the active fraction just as the soluble fraction of the fertilizers we put in the soil is generally regarded as the growth-promoting fraction.

We find (Fig. 9) that as we applied more nitrogen, more was taken up by the plant and more was found in the tissue. We find the same thing with regard to the soluble fraction. However, we note that whereas the plants in the medium and the low series showed progressive decrease in the soluble fraction from the top down towards the dry-leaf section, in the high-nitrogen series all the sections had about the same concentration. From this we will be justified in concluding that in the high series there was such an excess of soluble nitrogen that all parts of the plants were equally gorged with it.

We have now calculated the total pounds of N found in the top, the green-leaf and the dry-leaf sections of the mother and daughter stalks (we have seen before that these stalks make up 95 to 100 per cent of the total cane weight), and have expressed this amount on an acre basis (Fig. 10). We find that as long as the application of nitrogen was continued, i.e., up to the fourteenth month, the high series was taking up nitrogen at an even rate, the medium series almost as evenly, but in the case of the low series the rate fell off with age. We should recall how growth and yield also fell off in this series immediately after fertilization was stopped.

Knowing the amount of N applied to the soil and knowing the amount found in the plants* we can study the efficiency of uptake in the three series. In the lower part of Fig. 10 we have expressed the amount taken up as a per cent of the amount applied to the time of harvest.

Significantly, the uptake is 100 per cent or more in the low series showing that the plants must have actually drawn on the soil reserve. In the medium series, the uptake is about 75 per cent and only about 40 per cent in the high series. Evidently there is a limit to the plant's capacity to take up the applied nitrogen. If we now multiply the per cent uptake by the pounds applied, we find that the high series took up only about 260 pounds as against 200 pounds by the medium series and 140 pounds by the low series. The amounts found in the plants, therefore, give a much better idea of the relative yields of cane to be expected than the actual amounts applied to the soil.

At this point we venture to raise a question—"If we recover, say, about 80 per cent with an application of 266 pounds of N and fully 100 per cent or more with an application of 133 pounds, should we not find it profitable to apply a little less than 266 pounds, rather than an amount greater than this?"

We do no more than ask the question because we realize that the efficiency of utilization varies from year to year and from place to place. The man on the spot is, after all, the one best suited to answer the question for his locality and for his variety of cane.

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* We should mention that as we did not analyze the roots and the dry trash, our nitrogen balance is not exactly right but undoubtedly it is very close to being so as neither roots nor dry trash have much nitrogen or make up much weight.

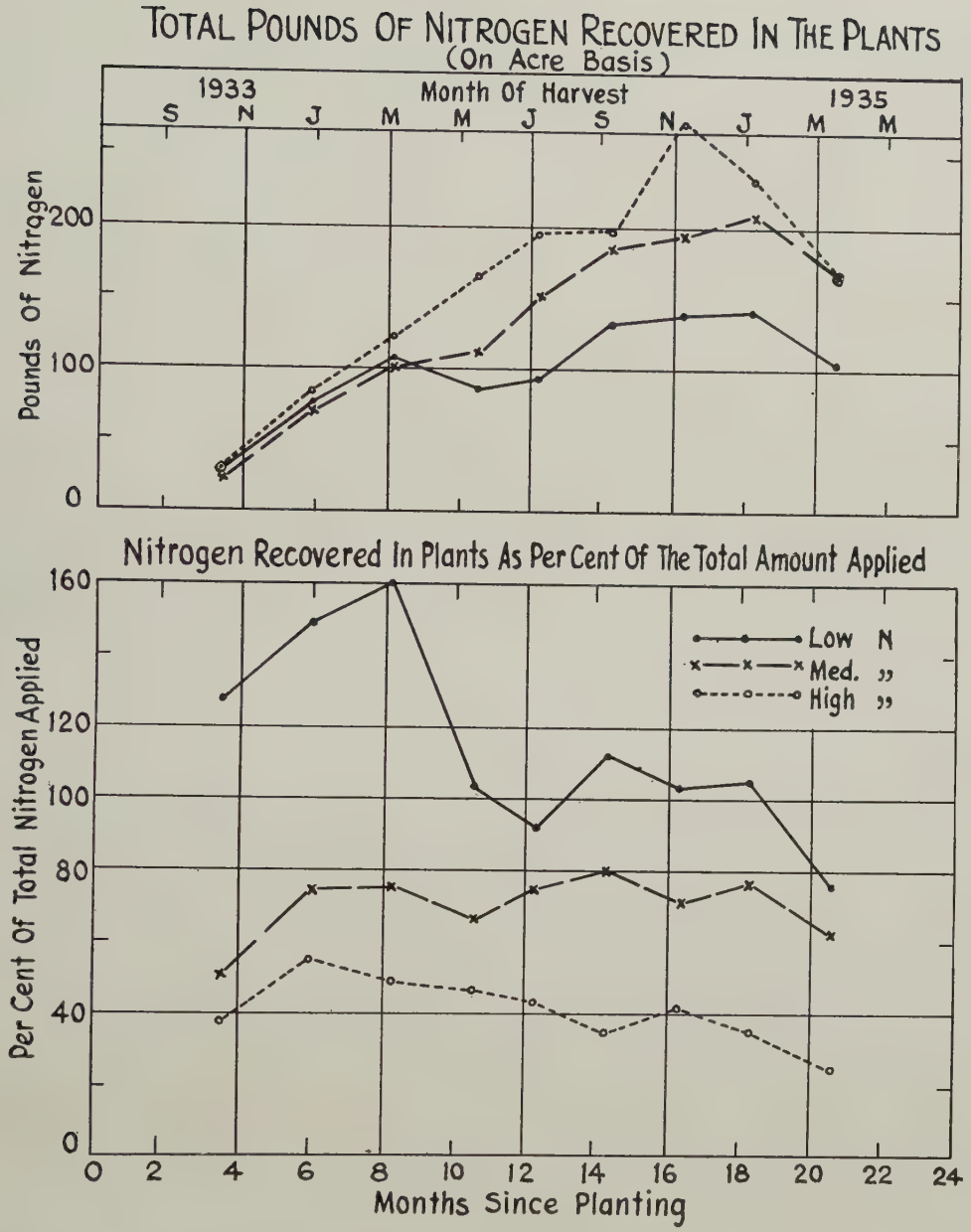
TOTAL POUNDS OF NITROGEN RECOVERED IN THE PLANTS
(On Acre Basis)
1933
Month Of Harvest
1935
S N J M M J S N J M M
Pounds Of Nitrogen
200
100
0
Nitrogen Recovered In Plants As Per Cent Of The Total Amount Applied
Per Cent Of Total Nitrogen Applied
160
120
100
80
40
0
Low N
Med. ,,
High ,,
0 2 4 6 8 10 12 14 16 18 20 22 24
Months Since Planting

Fig. 10

Electrical Conductivity—or the Amount of Electricity that a Sample of Juice Can Conduct

Those of us who have some familiarity with the chemical methods employed in the laboratory to determine the amount of various salts in the cane juice, such as muriate of potash, or ammonium sulfate, know that these determinations are rather arduous and time consuming. If we were not really very particular whether we knew the different kinds of salts that were present in the juice but contented ourselves with knowing the total amount of those salts, then we could dispense with the tedious chemical methods and employ one that is much simpler. Such a method consists in determining the current of electricity that passes through a solution such as cane juice. Investigators have found that an electric current passes with difficulty through pure water but if the water contains salts, such as muriate of potash, then the current flows more readily, the flow depending on the concentration of the salts.

We have made regular determinations of the electrical conductivity of juice and show the results in Fig. 11. We find that the top is many times richer in salts of the type mentioned than the green-leaf and the dry-leaf sections. We further note that after the application of nitrogen was stopped, the green-leaf and the dry-leaf sections tended to become alike with respect to salt concentration. Most interesting, however, are the data on the dry-leaf sections. Not only do we find that the higher the application of nitrogen, the higher the conductivity, but also there are definite seasonal rhythms very much like those which we found with respect to water content, sucrose and glucose. We therefore conclude that as we apply more nitrogen we increase the salt content of juice, but seasonal variations will predominate over treatment variations.

It will be recalled that we have already suggested that the differences in the water content might be really due to these differences in the salt content.

We should further observe that the conductivity of juice and sucrose content appear to be definitely related although in an opposite sense, i.e., when conductivity is high, sucrose content is low and vice versa. This is not surprising in view of the already discovered fact that the water content is related to sucrose content and also to conductivity.

The question we might ask now is, "What causes the seasonal differences in conductivity?" We do not know the answer for certain. However, much work is being conducted abroad on this topic and we hope that a definite solution will be given for this problem before long.

Acidity or pH of Juice

We also determined the pH of juice. In general the pH is higher as we go from the top down the stalk. As higher acidity is denoted by a lower pH value and vice versa, we conclude that the leafy top is the most acid and the dry-leaf section the least. In this latter section there appeared to be a slight increase in acidity as the cane became older. Some plants actually do store acids and thereby increase in acidity; whether or not the sugar cane plant does that to any extent we do not know. We shall study this point more fully in the future.

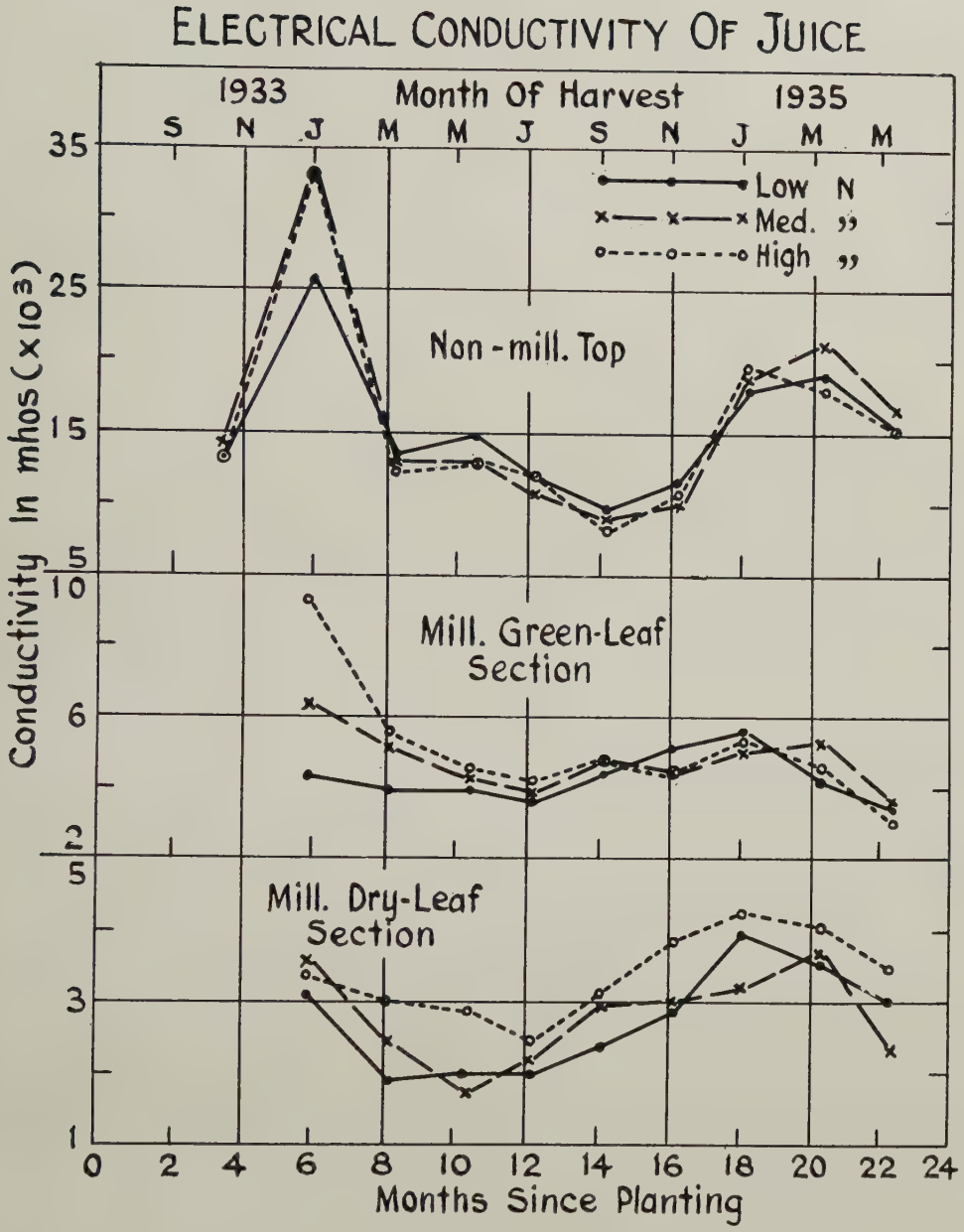
ELECTRICAL CONDUCTIVITY OF JUICE
1933
Month Of Harvest
1935
S N J M M J S N J M M
Low N
Med. ,,
High ,,
Non-mill. Top
Mill. Green-Leaf Section
Mill. Dry-Leaf Section
Conductivity In mhos (x 10³)
35
25
15
10
6
5
3
2
1
0 2 4 6 8 10 12 14 16 18 20 22 24
Months Since Planting

Fig. 11

Total Pounds of Sugar

We have seen that the cane tonnage is highest in the medium series from the eighteenth month on because of increasing mortality in the high series. If we now obtain from the data on tonnage and sucrose content the actual pounds of sugar in each line, we find that it is the highest in the medium series. The high series, on the other hand, is only slightly better than the low. Evidently what the low-N series lacks in tonnage it makes up in quality. The medium series is really the golden mean, where high tonnage is combined with fairly high quality. There is little novelty in this deduction for we know as a result of many field experiments that an amount of N around 266 pounds does give us the highest yield of sugar in the well-irrigated fields of Oahu. It is gratifying, however, to see our previous experience supported by a different approach.

The Whole Picture

In discussing the various topics, we have referred to the various inter-relationships; here we bring them together in a single picture. In Fig. 12 we show the data on nitrogen in the tissue, electrical conductivity of juice, water content of the tissue, and the concentration of sucrose and glucose in the juice of the dry-leaf section. We find general similarities in all the curves not only with regard to the differences between the series but also between seasons. We would like to draw particular attention to the data on the harvest in September (age fourteen months) for we feel that here may be a case where an apparent exception may prove the rule. We find that the medium series shows a sudden deviation, and that this deviation is present in all of the curves. Surely this could not be a mere coincidence; instead we feel it supports our contention that all the juice characteristics shown in Fig. 12 are in fact related.

It would appear here as if in the dry-leaf section the complexities stand partly unravelled, thus affording us a view of the many inter-relations through which nitrogen affects the quality of juice. The sequence of events, as we see it, is as follows—"Application of nitrogen increases the salt uptake as indicated by the electrical conductivity of juice. The greater salt content causes greater succulence, i.e., greater water content. The greater amount of water present has first a diluting effect on the juice and secondly, it may even determine as to whether the sugars formed by the leaves are to be stored as sucrose or as glucose." This picture may not be entirely correct; later experiments may modify our views as to which is the first cause and which the second, but we feel that the one presented may be taken at least as a working hypothesis.

Summary

We can sum up the high points of our experiment thus:

(1) The higher the application of nitrogen, the greater will be the tiller production, the greater the number of joints formed and the higher the rate of cane growth.

(2) The higher the application of nitrogen the greater the tonnage of cane. However, with excessive nitrogen, mortality of cane may be so great as to produce less cane than with a moderately high application.

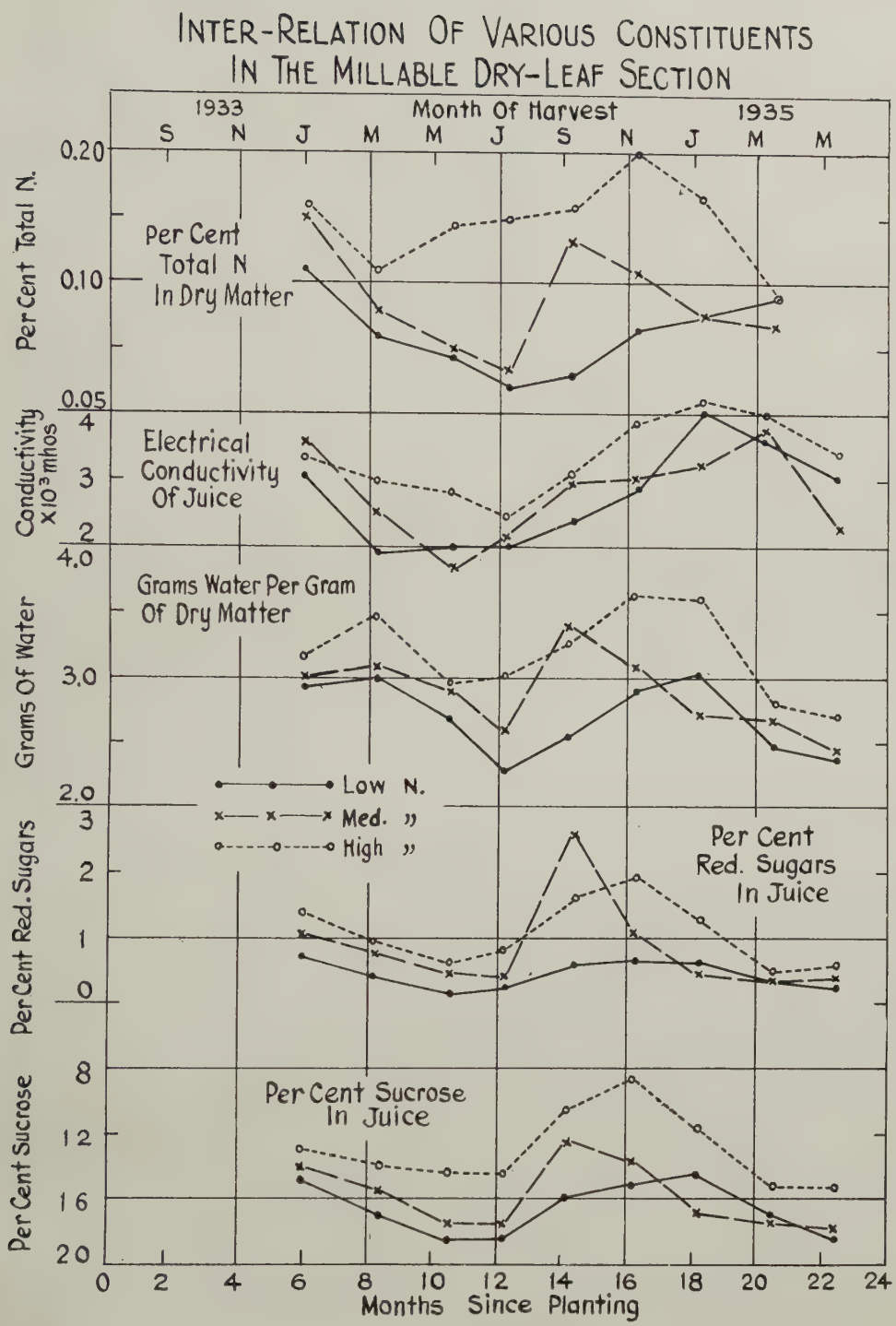
INTER-RELATION OF VARIOUS CONSTITUENTS
IN THE MILLABLE DRY-LEAF SECTION
1933
Month Of Harvest
1935
S N J M M J S N J M M
Per Cent Total N.
0.20
0.10
0.05
Per Cent Total N In Dry Matter
Conductivity x10³ mhos
4
3
2
Electrical Conductivity Of Juice
Grams Of Water
4.0
3.0
2.0
Grams Water Per Gram Of Dry Matter
Low N.
Med. "
High "
Per Cent Red. Sugars
3
2
1
0
Per Cent Red. Sugars In Juice
Per Cent Sucrose
8
12
16
20
Per Cent Sucrose In Juice
0 2 4 6 8 10 12 14 16 18 20 22 24
Months Since Planting

Fig. 12

(3) The more nitrogen applied, the greater the succulence, i.e., the water content, of plants. We suggest that the increased water content has two important functions: (a) it dilutes the juice, resulting in a lower concentration of sucrose with higher amounts of nitrogen, and (b) it probably determines whether or not the sugars manufactured by the leaves will be stored mainly as sucrose or a fair proportion of the sugars will be in the form of glucose.

(4) The greater the application of nitrogen, the poorer will be the concentration of sucrose in juice as well as in the water-free tissue, while the concentration of glucose is just the reverse.

(5) The highest amount of sucrose is obtained from moderately high applications of nitrogen. An excessive application of nitrogen, as in our high series, produces such poor juice as to largely offset the advantages of increased tonnage.

(6) The greater the application of nitrogen, the greater the nitrogen content of the tissue. The efficiency of uptake of nitrogen decreases as the amount applied is increased. With low applications fully 100 per cent may be recovered in the plants, while with excessive applications as in our high series only about 40 per cent is found in the plants.

(7) The electrical conductivity of juice (which is a measure of dissolved salts such as muriate of potash) increases with increasing applications of nitrogen, indicating that nitrogen stimulates the absorption of salts. We suggest that the increased salt content might be the reason for the increased succulence of plants receiving greater amounts of nitrogen. Electrical conductivity and sucrose content of juice appear to be oppositely related to each other.

(8) Although not clear in the details, yet we can discern the broad outlines of a rather simple picture. Increasing applications of nitrogen appear first to increase the salt absorption by the plants, the increased salt content probably causing greater water content or succulence of tissue. The greater water content has a diluting effect on juice resulting in a lower concentration of sucrose. This increased water content may even favor the storage of sugars such as glucose at the expense of sucrose.

There are many other points of interest which have come out in this study, points that largely confirm our past observations and our existing cultural practices. Many points need yet to be clarified before we can feel entirely at ease regarding the possible influences of nitrogen fertilization on quality. This study has given us many good leads and it is our purpose to follow these carefully.

Biological Control of the Sugar Cane Leafhopper in Hawaii

By O. H. Swezey

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Foreword

In the lengthy campaign for the biological control of the sugar cane leafhopper in Hawaii, much has been published from time to time concerning the occurrence of the leafhopper in Hawaiian cane fields, studies of its life history, etc., and separate accounts of the introduction of the various parasites. Now that the leafhopper has been under satisfactory control for many years, and there is every reason to believe that this situation will continue, it is well that a connected account be given of the history of the occurrence of this pest in Hawaii, and the history of the introduction of the various parasites with details of their methods of attack and relative importance in the ultimate control of so serious a pest, which in 1903-04 threatened to ruin the sugar industry in Hawaii. The present paper is an effort to assemble briefly what has been accomplished, and how, with numerous references to literature where fuller details have been published in due course. The illustrations have often appeared in previous publications by the Experiment Station, H. S. P. A.; in bulletins from the Entomology Department; in *The Hawaiian Planters' Record;* and in the volume on "Insects and Other Invertebrates of Hawaiian Sugar Cane Fields," by F. X. Williams.

Early History of the Leafhopper in Hawaii

The sugar cane leafhopper* (8, p. 179) in Hawaii was a pest of foreign origin. Its first observance in Hawaii was made by Dr. R. C. L. Perkins when taken at light in his room at Waialua, Oahu, in the latter half of 1900. It was recognized at the time as an immigrant insect, not previously seen, but its habits or importance were not known until about a year later. Dr. Perkins had spent a number of years in collecting insects on the various Islands, beginning in 1890, and although he had collected many species of endemic leafhoppers, he had not previously seen this one, which, while related to the native leafhoppers, yet was distinctly different. Later, when its importance became evident, Dr. Perkins concluded that it must have been quite a recent introduction, or he would have noticed it sooner. He considered that it must have been introduced two or three years prior to 1900.

The first record of the leafhopper attacking sugar cane is found in the annual report of Albert Koebele for the year 1901 (14, p. 21). In this report he mentions E. G. Clarke, then Agriculturist at the Experiment Sation, H. S. P. A., as reporting the appearance of the leafhopper on sugar cane at the Experiment Station some twelve months previously. This would have been either late in 1900 or early in 1901, not long after, or about the time when Dr. Perkins took specimens coming to light at Waialua. It must have been present in the cane fields at Waialua at that time, without its presence having yet become known. In Mr. Koebele's report, Demarara and Rose Bamboo were the varieties of cane affected. He described the characteristic appearance of cane when badly attacked, viz., the black and dirty leaves caused by the excreted honeydew in which sooty mold flourishes, and the red midribs

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* *Perkinsiella saccharicida* Kirkaldy. (The numbers in parentheses refer to literature cited.)

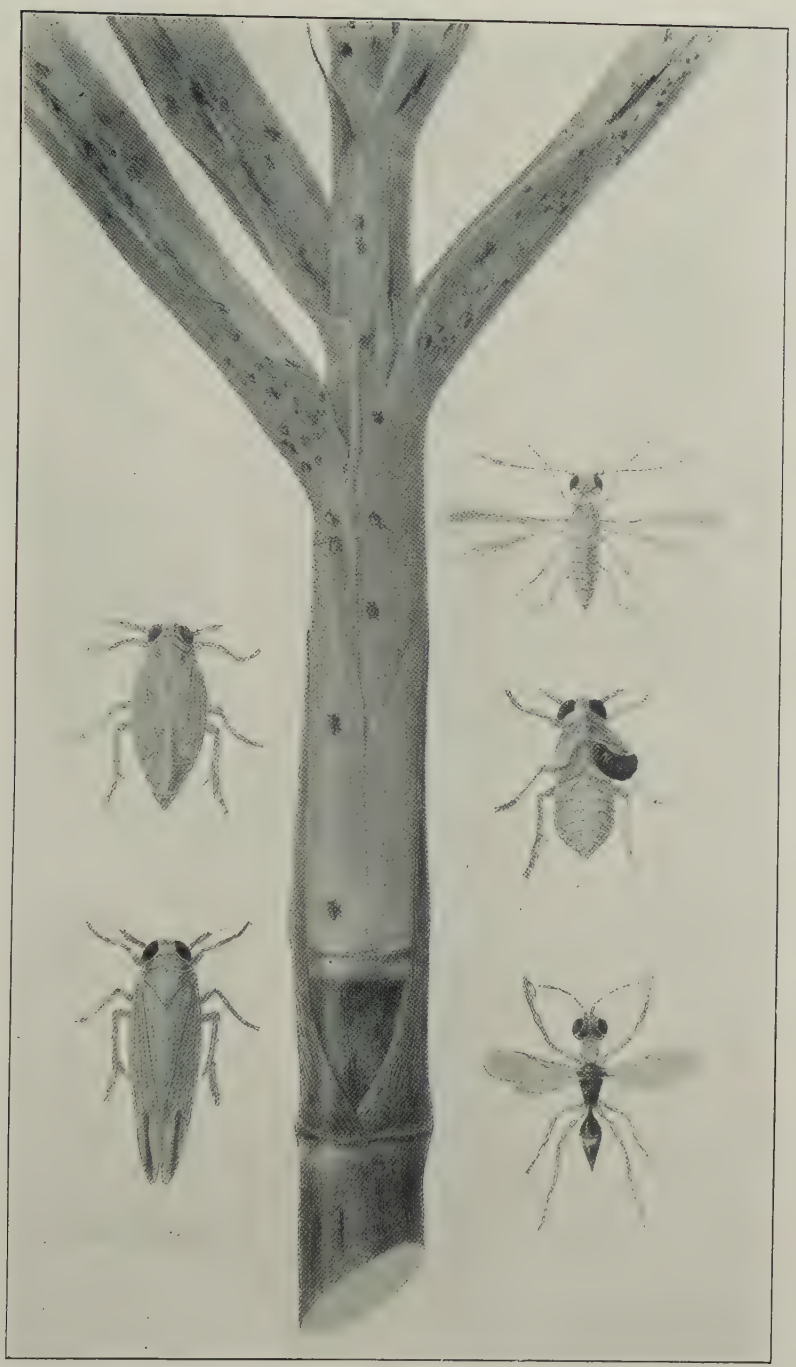

Plate 1. Sugar cane leafhopper *(Perkinsiella saccharicida).*

Center: Sugar cane stalk infested with leafhoppers; at left, adult leafhoppers, long-winged and short-winged, enlarged; upper right, egg parasite *(Paranagrus optabilis)* greatly enlarged; right intermediate, young leafhopper showing black larval sac of Fairchild's parasite, considerably enlarged; lower right, Fairchild's parasite *(Echthrodelphax fairchildii),* adult female, considerably enlarged.

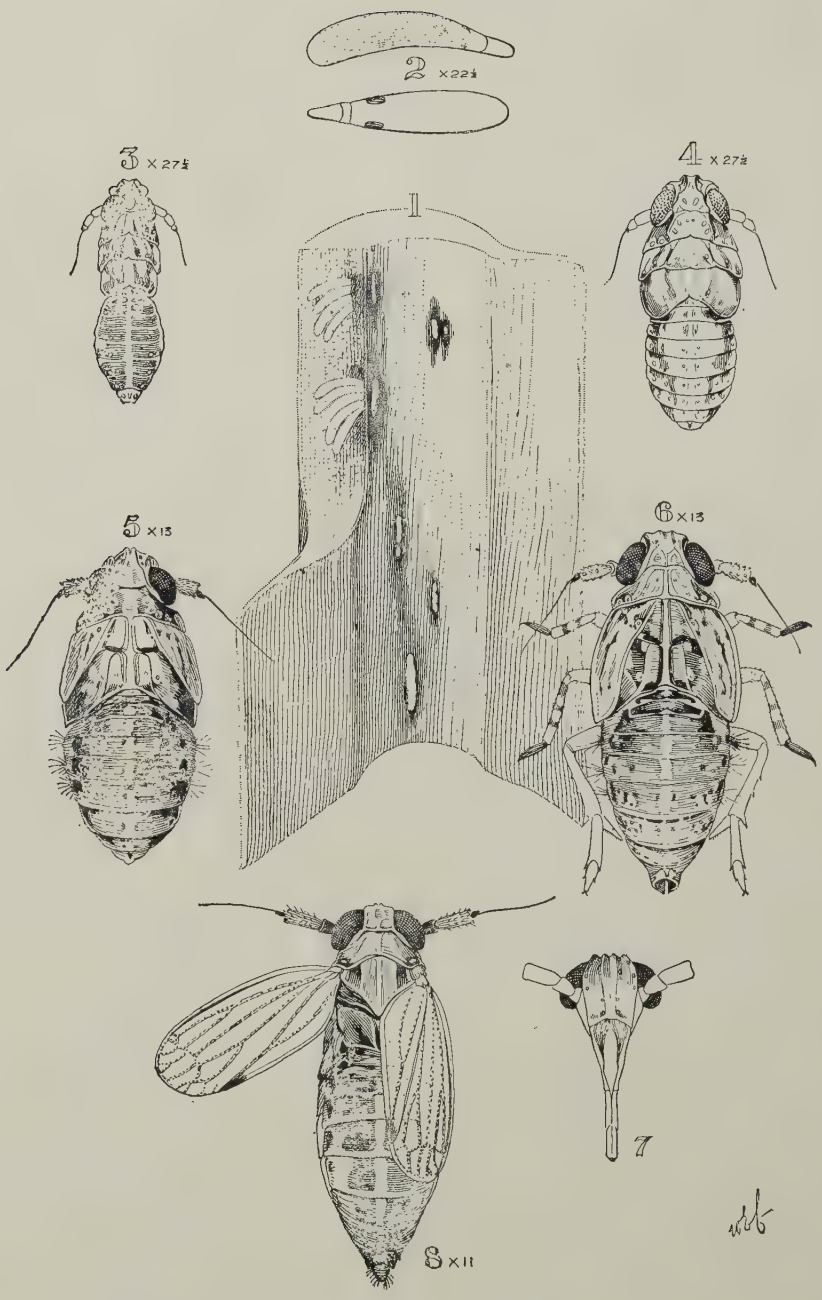

Plate 2. Sugar cane leafhopper *(Perkinsiella saccharicida)*.

1. Eggs in sugar cane midrib, those at the side being shown somewhat in profile and in section.
2. Eggs isolated, highly enlarged.
3. Nymph or young of first instar.
4. Young, second instar.
5. Young, third instar.
6. Young, fourth instar.
7. Face of the same.
8. Adult female, short-winged form.

of the leaves caused by the fermentation taking place at the injuries where the leafhopper eggs were inserted in large numbers.

Attention having been brought to these conditions, the presence of the leafhopper was soon made known on all plantations of Oahu.

Dr. Perkins in a paper, "Notes on insects injurious to cane in the Hawaiian Islands" (31), stated that the leafhopper was ubiquitous on Oahu in 1902 and also known on Kauai, and known only from these two Islands. It was already recognized as a serious cane pest, the destructiveness of which threatened to exceed that of the cane borer beetle. Dr. Perkins advised that care should be taken to prevent its spread to the other Islands, if it were not already established there. However, it must have been already established for some time on these Islands, for D. L. Van Dine (57, p. 8) has reported that his attention was first called to it on Maui by Hon. H. P. Baldwin on cane at Puunene, August 12, 1902; and early in 1903 it was reported from some of the sugar plantations on Hawaii, where it had already become conspicuously injurious to the cane.

The manager of Paauhau Sugar Plantation Company on Hawaii reported its first appearance about the end of February and again on May 28, 1903, he reported it "on every acre of the plantation."

Early in June 1903, Mr. Van Dine (57, p. 8), the entomologist at the Hawaii Agricultural Experiment Station in Honolulu, visited Paauhau after having spent two weeks studying the habits of the leafhopper in the Kohala cane fields. He pronounced the leafhopper infestation worse there than in Kohala. Several plantation managers of the Hilo and Hamakua districts also visited Paauhau to examine the leafhopper injuries. All pronounced this the most severely infested plantation, although the leafhopper was present throughout the plantations on the windward coast of Hawaii, but not yet injuring the cane as at Paauhau, where some fields of cane were severely checked in growth. Yellow Caledonia was the principal cane grown in the Hilo district and it was injured less than the Rose Bamboo cane, which in turn was more severely injured at Paauhau than was the Yellow Caledonia cane grown in the same place. At this time the plantations at Ookala and Hamakua were infested about the same as at Paauhau.

Dr. Perkins visited Paauhau, Honokaa and Kukuihaele, June 17-24, 1903, and made studies of leafhopper conditions and of the natural enemies which were already increasing in the fields and helping to check the leafhopper. The results of his observations were published in a bulletin (32) soon after.

The most severely injured plantation on the Island was the Hawaiian Agricultural Company at Pahala, where the Yellow Bamboo cane was the variety chiefly grown, and it proved to be more susceptible to leafhopper attack than any other variety. The damage was so extensive here that whole fields of great area were practically killed outright, and the plantation, which had a sugar crop of 18,888 tons in 1903, was reduced to crops of 1,620 tons in 1905 and 826 tons in 1906. These two latter crops were from cane that was growing and was practically ruined in the worst leafhopper years, representing a loss of over a million dollars each year.

In 1904, replacement of Yellow Bamboo was begun by planting the Yellow Caledonia variety as extensively as possible, and for a few years this variety in-

creased by about 2000 acres annually, resulting in bringing the Hawaiian Agricultural Company back to a sugar crop of 11,630 tons in 1907 and about that same amount for several years after, but not up to its pre-leafhopper yield for about 7 years. As previously stated, the Yellow Caledonia variety was not so severely injured by leafhopper attack, even though the pest was present in enormous numbers, so that when this plantation became largely planted to the Yellow Caledonia cane not much loss was involved.

At the time of maximum leafhopper damage, the total annual output of sugar from all plantations dropped from 437,991 tons to 367,475 tons, a difference of 70,516 tons, equivalent to a loss of over five million dollars. This occurred within two years of the time that the leafhopper was first known on sugar cane, which shows how quickly it rose to prominence. Of course, as stated by Dr. Perkins above, the leafhopper must have been present in the cane fields for several years without being noticed. There were no entomologists making regular visits to the plantations in those days, or its presence would have been known sooner. Apparently as soon as attention was called to it, it was already to be found in all districts.

Just how or when the leafhopper arrived in Hawaii can never be determined, but it is very evident that it came along with importations of cane cuttings for planting. Dr. Perkins (31, p. 595) related having examined a consignment of cane cuttings from Queensland containing eggs of a leafhopper, and that a few young leafhoppers were present, having hatched on the journey. (Needless to say, the package was destroyed.) It is quite likely that at some previous time infested cane cuttings were received and planted. The Yellow Caledonia and Rose Bamboo varieties were introduced from Queensland about 1880 (5), together with several other varieties which were planted in the Kau district of Hawaii. After growing there for several years these varieties were distributed to other districts. It is very probable that among the original consignment there were some canes containing leafhopper eggs, which hatched after planting, and some of the young survived to reach maturity on the new shoots of cane and succeeded in becoming established there. From this small beginning they had no doubt increased to such an extent that when cuttings were distributed elsewhere a few years later they all contained a few leafhopper eggs and in this way the pest became widely spread and would have had ample time to have already reached destructive abundance when found in 1902.

(For an account of the difficulty in getting the determination of this leafhopper, see page 64.)

Plans for Introduction of Parasites

The Hawaiian Sugar Planters' Association had no entomological department at this time (1902). Mr. Koebele was government entomologist and had been introducing ladybeetles and parasites for scale insects, mealybugs, aphis, etc., since 1893, and in 1902, when it was realized that the leafhopper was a serious pest, was on an expedition to Mexico (May to December) studying the insects attacking lantana there and endeavoring to introduce some of them into Hawaii. The sugar planters were so much concerned that they wished Mr. Koebele recalled and a

start made on locating and introducing parasites for the leafhopper. The situation is expressed by Dr. Perkins, who was assisting Koebele by handling the consignments of insects sent to Honolulu, in a letter to Koebele dated October 24, 1902:

> The Sugar Planters are now very much concerned about the leafhopper and some are shouting for your recall. I wrote my view of the matter to Mr. Tenney at his request. . . . I have taken all possible means to obtain some preliminary knowledge about this leafhopper, without which we should be acting blindly. To myself the matter appears very important. If the lantana business is not completed this year I think it could be continued at some other time, for both the ranchers and others are keen about its succeeding. I don't expect you now to get through until January, owing to the failure of the last lots, due to delayed arrival. . . . Of course, you will do what you yourself think best about returning for leafhopper. It really is serious, probably hundreds of thousands of dollars will be lost on the future crop and much more later on.

In Mr. Koebele's reply to this letter, dated November 23, 1902, from Cuernavaca, Mexico, he says:

> I am very sorry about the increase of the sugar cane leafhopper and fear it will be another hard problem. Yet it is not like this lantana question, being only a simple matter of finding some efficient enemy or parasite. If any such exists it must be hunted up; if not, there is not much to be done, but I should think something can be found. As to the leafhopper, I should advise you to send specimens to Dr. Treub, Director of the Botanical Gardens, Buitenzorg, Java, and ask if they know the species. . . . The end of January ought to see me in Honolulu to start without delay in search of enemies for the cane leafhopper.

Again, in a letter of November 26, Mr. Koebele writes on the leafhopper problem:

> On my return I shall not stay in Honolulu for any length of time, but shall start as soon as possible on that leafhopper business and I hope you will remain, while I am away on this matter. (This latter remark was because Dr. Perkins had made plans for a trip to England.)

Mr. Koebele had been seriously ill several times while in Mexico, and when he returned to his home in Alameda, California, in December, he was suffering from a bad attack of fever. He wrote December 26:

> I am still unwell, not yet over my fever, but a rest may help me and I am only too glad to be out of Mexico and rid of the hardest work that I ever did.

Instead of returning to Honolulu as soon as he had planned, it was necessary for him to remain in Alameda for recovery. Hence, his plan for early return to Honolulu and a start on search of leafhopper enemies was not fulfilled. After having recovered from fever, some study was made of parasites of leafhoppers in California and Ohio.

Koebele's Work in Ohio

Mr. Koebele went to Ohio on the advice of Dr. L. O. Howard, Chief of the U. S. Bureau of Entomology, to look up certain dryinid parasites which had been discovered by the writer (at that time a research student in Entomology at Ohio State University, Columbus, Ohio), working on certain leafhoppers in the fields of Ohio. An account of these parasites was printed in *The Ohio Naturalist,*

Vol. III, pp. 444-451, pls. 20-21, 1903. Upon Mr. Koebele's arrival in Ohio in August 1903, the writer worked with him a short time, showing him the situations where parasitized leafhoppers had been obtained, etc. Mr. Koebele worked the rest of the summer in Ohio, collecting and breeding leafhopper parasites for shipment to Honolulu. Besides those already known, he discovered several other kinds of parasites on leafhoppers. The parasites already known were Dryinidae: *Dryinus ormenidis* Ashm., living on the young of *Ormenis septentrionalis* Spin., and *Gonatopus bicolor* Ashm. (later described as a new species by Dr. Perkins under the name *Haplogonatopus americanus* [35, p. 40]), living on the young of *Liburnia lutulenta* Van D. Mr. Koebele discovered several other species of dryinids working on leafhoppers. He reared these parasites by the hundreds to the cocoon stage, in which condition they were sent to Honolulu. Cocoons of several species were sent, but none of them was ever known to have become established on the sugar cane leafhopper, although two species did attack the cane leafhopper and were reared to maturity in captivity and their offspring liberated in cane fields.

Other leafhopper parasites discovered were the egg parasite *Anagrus columbi* Perk., parasitic on *Liburnia* eggs; a minute stylopid of the genus *Elenchus;* and one instance of parasitism by a dipterous maggot of the genus *Pipunculus.*

Although no parasites became established in Hawaii from Mr. Koebele's studies in Ohio, the knowledge gained of the kinds of parasites that attack leafhoppers became of great value in later work with leafhopper parasites. What special kinds of parasites to look for was known when search was made in Queensland cane fields.

The Leafhopper Determined as a Queensland Species

Considerable time elapsed before the identity of the cane leafhopper had been determined and it was ascertained from whence it came. From a study of the literature available in Honolulu at that time, Dr. Perkins stated in a report of October 23, 1902 (quoted in 32, p. 7) that he was certain it was not any of the species of leafhoppers known to attack cane in other countries. At the same time he called attention to the similarity in habits between the species in Hawaiian cane fields and the species in Javanese cane fields, *Dicranotropis vastatrix* Bred.:

> Finally, after much correspondence with other countries, the matter was conclusively settled for me by Mr. Kirkaldy, who obtained from Germany cotypes of the Javanese insect described by Breddin and found it to be quite distinct from the Hawaiian one. Other authorities considered the Javanese insect and ours identical.
>
> Meanwhile I was also corresponding with Australian entomologists in the hope of procuring specimens of a Queensland cane-infesting leafhopper for comparison with ours; but it was not till some six months after I began this correspondence that I had the great satisfaction of receiving from Mr. James Clark of Cairns, four specimens of this Queensland species, which proved to be the same as our own. Mr. Clark also informed me that this leaf-hopper had been known there for years, that it was their only species, that it did no noticeable damage and was probably kept in check by some efficient natural enemy.
>
> As I have mentioned in former reports the fact that leaf-hopper was present on cane in Queensland was discovered by me when inspecting some seed-cane imported from that country, the said seed-cane containing numerous eggs of a leaf-hopper, while a few very young insects were also present. These not being at a stage of development when their identity with our own species could be decided, it was only on receipt of Mr. Clark's specimens that this was finally settled.

It was found that the species of the Queensland leafhopper had not been determined. Already Kirkaldy had described the leafhopper in Hawaiian cane fields as a new species for which he also erected a new genus—*Perkinsiella saccharicida,* being the name of this leafhopper as published in *The Entomologist,* Vol. 36, p. 179, July 1903. (Many more species of the genus *Perkinsiella* were discovered later, occurring on sugar cane in various regions. For list, see Appendix A.)

Organization of Division of Entomology

At the time when the leafhopper came into prominence as a sugar cane pest in Hawaii, there was no provision for work in entomology at the Experiment Station of the Hawaiian Sugar Planters' Association. Mr. Koebele was the Superintendent of Entomology, working under the Board of Commissioners of Agriculture and Forestry, and he had as assistant Dr. Perkins, who had spent most of the time since his arrival in the Islands in 1892 in collecting and in working on material for the *Fauna Hawaiiensis,* which in the main deals with insects. At the Hawaii Agricultural Experiment Station, Mr. Van Dine was staff Entomologist.

Early in 1903 the work of the Board of Agriculture and Forestry was reorganized in order to give more attention to the inspection of imported vegetable matter, and prevent as far as possible any further introduction of insect pests by way of the port of Honolulu. As Mr. Koebele was away most of the time in search of beneficial insects, Dr. Perkins was really in charge of this work. Late in the same year, Messrs. G. W. Kirkaldy and F. W. Terry were added to the staff to assist in inspection work. All of this work was carried on by an arrangement with and mostly at the expense of the Hawaiian Sugar Planters' Association, under which agreement much of the time was to be devoted to the study of sugar cane pests and the search for and introduction of beneficial insects to combat such pests. Of course the leafhopper was of most importance in this respect. Mr. Van Dine, of the Hawaii Experiment Station, had also given some attention to the study of the pest.

In 1904 the pest had assumed such importance that it became apparent that the Hawaiian Sugar Planters' Association should conduct the campaign against it independent of other institutions. Accordingly plans were started for organizing a Division of Entomology at the Experiment Station, H. S. P. A. When this organization was completed in the middle of the year, the entomologists of the Board of Agriculture were taken over by the newly formed Division of Entomology, the staff of which was made up as follows: R. C. L. Perkins, Director; Albert Koebele, Consulting Entomologist; G. W. Kirkaldy, Assistant Entomologist; F. W. Terry, Assitant Entomologist. In August 1904, O. H. Swezey was engaged especially for breeding parasites and plantation inspection work, and later had charge of the distribution of parasites to plantations and the progress of their establishment and spread in the fields. Mr. Swezey was specially qualified for this work by his previous experience with leafhoppers and their parasites in Ohio. In the summer of 1905, soon after his return from the Australian leafhopper expedition, Mr. Koebele retired from active field work after a long career, leaving Honolulu not to return, and Frederick Muir was engaged for the continuance of foreign entomological explorations, for which he was well adapted.

Thus at its beginning and during its early years, the Division of Entomology at the Experiment Station, H. S. P. A., became equipped with a competent staff of entomologists (there were changes from time to time in later years) for coping with the leafhopper and other insect pests of the cane fields; the results of which have been in evidence in these later years when the plantations of Hawaii have been much less subject to insect depredations than other sugar cane countries. Indeed, some of the once-serious pests are so scarce as to be found only with difficulty on many of the cane lands of Hawaii.

The Perkins and Koebele Expedition to Australia

With the knowledge that the cane leafhopper had undoubtedly come as an immigrant from Australia, where it did no noticeable damage on account of probably being held in check by natural enemies, plans were made for an expedition to Australia for special study of leafhopper parasites after Mr. Koebele's return to Honolulu from his summer's work in Ohio in 1903. Mr. Koebele spent some time in California, where additional information was obtained concerning parasites of leafhoppers, before coming on to Honolulu early in 1904. The Australian trip started May 11, 1904, Dr. Perkins accompanying Mr. Koebele. The parasites which were discovered and successfully introduced are discussed in detail in subsequent pages. It will be appropriate to quote here from general remarks by Dr. Perkins (35, pp. iii-iv) on their itinerary, etc., which occupied the rest of the year:

> Early in June we arrived at Brisbane and on the first cane that we saw, a few plants in the public gardens, we at once observed the presence of the cane leaf-hopper. A short stay of about ten days gave ample proof of the existence in Australia of a considerable variety of Hymenopterous parasites of leaf-hoppers, of Dipterous parasites of the genus *Pipunculus*, and of Stylopid parasites of the genus *Elenchus*.
>
> At Bundaberg, about twelve hours by rail north of Brisbane, we spent another ten days in June. Here is an extensive cane district with our leaf-hopper everywhere present, but never in numbers such as we are accustomed to in these islands. In fact we never saw the hoppers nearly as numerous as they are on our least affected plantations. From eggs collected here Mr. Koebele soon bred out specimens of the Mymarid parasites he had felt so confident of finding.
>
> From our observations on the habits of the cane leaf-hopper in these islands, it seemed probable that in tropical Australia this species would be in its greatest numbers in the colder months, so after a brief stay in Bundaberg, we proceeded north to Cairns, which place we reached at the beginning of July. This plan seemed very expedient, for by retreating gradually towards the south, as the hot season advanced, we hoped to prolong the season during which natural enemies for the cane leaf-hopper could be obtained. It appeared likely that effective work could only be done at Cairns for a month or two, since without a reasonably large supply of hoppers, it was evident that the parasites could not be found in sufficient numbers for shipment. This indeed proved to be the case, and by the end of August, leaf-hoppers and their eggs had become so scarce in the cane-fields, that we came south again to Bundaberg. At Bundaberg we made a long stay on this occasion, regularly sending off consignments of parasites, until here too, owing partly to the season and partly to the harvesting of the crop, the locality became unprofitable. After a short stay in Brisbane, at the end of the year, I returned to Honolulu, while Mr. Koebele proceeded to Sydney, where his attention was largely given to collecting beneficial insects for pests other than leaf-hopper. On the return journey Mr. Koebele spent one month in Fiji, the enemies of the cane-hopper in those islands being mostly similar to those already found in Australia. A fine consignment of the Chalcid egg-parasite (*Ootetrastichus*) of leaf-hopper was most important, as it enabled us to establish that important species without any doubt.

Paranagrus optabilis Perkins (35, p. 199) (Mymaridae)

This is the most important of the several leafhopper egg parasites that were introduced. It was discovered by Koebele in June 1904, in the Queensland cane fields at Bundaberg. It was later found at other places in Queensland. In the first attempts at introduction, four consignments of this parasite were sent from Cairns, Queensland. The material sent consisted of small cuttings of midribs of cane leaves containing parasitized leafhopper eggs, packed in damp Sphagnum moss in small boxes, and placed in the cool-chamber on the steamer. Apparently none survived from these consignments. Subsequent consignments sent from Bundaberg were more successful, and a few parasites issued after arrival in Honolulu. It is not

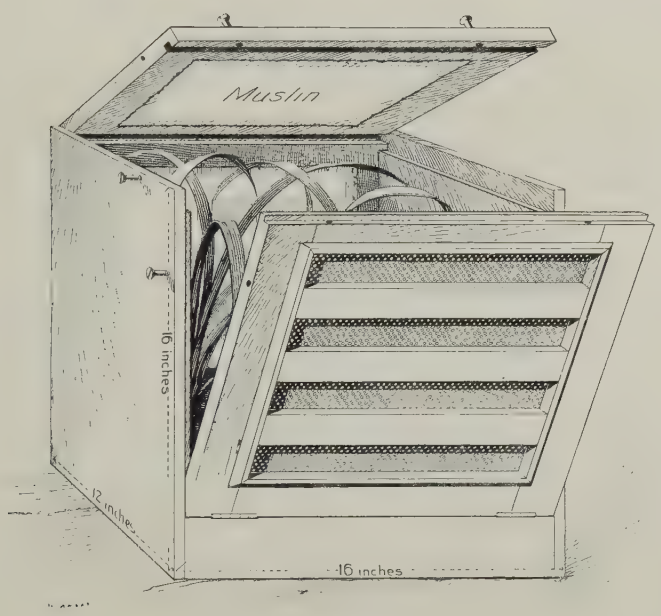

Fig. 1. Shipping cage for egg parasites.

certain that anything was accomplished however, until consignments were made in cages of living cane plants with leafhoppers breeding thereon and the parasites breeding in the leafhopper eggs. It is probable that this parasite became established from eight females which issued from one of these cages from Bundaberg. The cage (Fig. 1) arrived December 14, 1904. An occasional parasite issued at intervals. The eight females mentioned above were found in the cage by Dr. Perkins on January 26 and 27, 1905. Four of the parasites were liberated in the Experiment Station grounds, and four were transferred to a breeding cage consisting of a large glass battery jar (Fig. 2) containing a young, growing cane plant, in the leaves of which leafhopper eggs had previously been deposited.

At the end of three weeks the first brood of parasites began to appear, and, in all, 47 individuals, all females, were obtained. Half of these were liberated, the rest being used to stock a number of new breeding jars similar to the first. From these a very large number of individuals were reared and were treated in various ways. Some were "sleeved" out in the fields on growing cane containing many leafhopper eggs (Fig. 3). In the insectary large colonies were reared on large cane plants in tubs (Fig. 4), and still larger cages were used in the field where several leafhopper-infested stools of cane could be covered (Fig. 5). All of these methods were successful in breeding *Paranagrus* and other egg parasites as well.

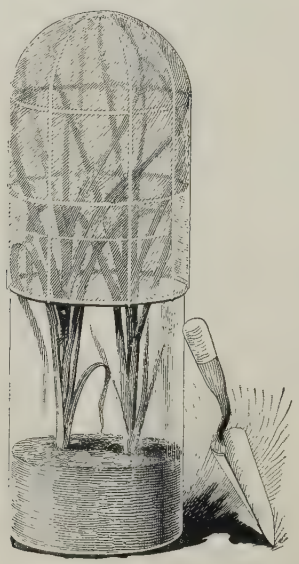

Fig. 2. Battery jar breeding cage for egg parasites.

While the parasites were still comparatively scarce and not easily obtainable in numbers for distribution, they were sent out in colonies in the large battery-jar cages mentioned above. Several of the plantations were supplied with these cages in April and May, 1905. The jar was placed by an entomologist in the desired cane field, properly protected from ants, a shade arranged for protection from sun and rain, then the cover of the cage removed so that the maturing parasites could go to the surrounding cane to parasitize the leafhopper eggs, which were numerous in the leaves. In this manner *Paranagrus* was first established on a number of the plantations. Subsequently, when the cane in the Experiment Station grounds became well stocked with the egg parasites, numerous colonies were sent out by using cuttings of midribs of cane leaves well filled with leafhopper eggs, many of which would be parasitized, placing the cuttings in a simple wooden cage to be suspended in the cane field where the parasites, which might issue daily for several days, could find fresh leafhopper eggs in the surrounding cane. By this method the parasite was

finally generally distributed throughout the cane districts during the latter half of 1905.

In some of the cane fields first colonized, the parasite was found already established the latter part of 1905. During 1906 it was found established and generally spread throughout the cane districts. In 1907, wherever leafhopper eggs could be found, a good percentage, often a high percentage of them were found to be parasitized by *Paranagrus*. The leafhopper had been greatly reduced due to the combined action of this and other introduced egg parasites, and other natural enemies already present in Hawaii.

Fig. 3. Sleeve cages in field, for breeding egg parasites.

Paranagrus was especially effective against the leafhopper on account of its short life cycle, which was less than half as long as the life cycle of the leafhopper—about 6 weeks in the latter and 3 weeks or less in the former. With each, the length of life cycle varies with the season of the year, being longer during the cooler part of the year and in the normally colder regions of the Islands. Successive broods follow throughout the year. In the insectary in July, adults issued in from 15 to 20 days after oviposition, an average of about 18 days, which would allow for about 20 broods per year. Some experimental breeding in the field at high elevations on Hawaii,

Fig. 4. Tub cages in insectary.

Fig. 5. Large cage over cane in field for breeding egg parasites.

2150-2650 feet, February to May 1918, indicated a life cycle lengthened from 42 to 73 days, or only 5 or 8 broods per year.

Another advantage is that *Paranagrus* is chiefly parthenogenetic, and breeding of this parasite in the insectary went on for 8 months, producing about a dozen broods, before any males were observed.

Fig. 6. Leafhopper on cane leaf, also *Paranagrus optabilis* in the act of ovipositing in inserted leafhopper eggs (highly enlarged).

The leafhopper places one to a dozen eggs in each egg puncture in the cane leaf, and while ovipositing (Fig. 6) the female *Paranagrus* may insert one of her eggs into each one of these eggs. Only one egg is inserted in each leafhopper egg, or at any rate, only one develops to maturity. The parasite larva develops right in the egg contents, there being just the proper amount for normal growth. Pupation takes place within the leafhopper egg shell, and when the parasite has matured it issues from the outer end of the egg shell, without gnawing a hole, as some of the other parasites do. Hence, it is not so easy to determine at a glance whether *Paranagrus* have issued from the leafhopper eggs in infested leaves. The leafhopper eggs when parasitized by *Paranagrus* have a pinkish color which changes to a lemon yellow when the developing parasite reaches the pupal stage. By splitting a leaf containing leafhopper eggs, it is easy to distinguish by this coloration how many, or what proportion are parasitized by *Paranagrus;* thus the percentage of parasitism could be calculated in the field. Another method of determining the percentage of parasitism was to take cuttings of midribs with leafhopper eggs, confine these in a glass jar for a time, and count daily the leafhoppers hatching and the adult parasites which issued.

It was found that *Paranagrus* would issue from leaf cuttings for a period of three weeks. Advantage was taken of this fact by several plantations to distribute *Paranagrus* on an extensive scale to new fields of cane. As soon as leafhoppers had migrated to these new fields and the young shoots were stocked with leafhopper eggs, these fields were supplied with numerous cages, regularly arranged, containing cuttings of midribs from fields where *Paranagrus* was known to be abundant. From these cages, which were arranged under a shelter, the parasites on issuing could parasitize the leafhopper eggs in the young cane and thus become established earlier, and sooner check the leafhopper, although it was always found that after the parasite was thoroughly established on the plantations they themselves were always able to migrate early to new fields, even when of great area, almost as soon as the leafhoppers had migrated there.

On several plantations buildings were erected as parasite hatcheries for obtaining *Paranagrus* in large quantities to be liberated in fields where the parasite was not sufficiently abundant to be effective, thus endeavoring to augment its usefulness. In these hatcheries, compartments were regularly supplied with cuttings of midribs from the cane fields where *Paranagrus* was most abundant. The compartments were darkened and adapted for accumulating the freshly issued *Paranagrus* adults in glass jars which could be taken to the desired fields for liberation of the parasites. They were handled by millions in this manner.

Notwithstanding these methods of distribution of the parasite, and the ability for dispersal of the parasite itself, and the fact that in most regions the leafhopper had become satisfactorily controlled, there were plantations on which, even 12 years after the introduction of this parasite, there were times and certain fields in which very severe outbreaks of leafhoppers occurred, resulting in diminished crops and great concern on the part of the plantation managers as to why the parasite failed in effectiveness in these instances. This concern resulted in search being made for more natural enemies of the leafhopper in 1919 and the ultimate introduction of the egg-sucking bug *Cyrtorhinus mundulus* in 1920. (See page 79.)

A species of *Paranagrus* not readily distinguished from *optabilis* was introduced from Formosa in February 1916 by Dr. Muir, who brought back cuttings of midribs containing leafhopper eggs. A notable distinction when the parasite was being reared for distribution was a greater proportion of males than had been noticed with *optabilis*. Breeding of this parasite was not carried on very long, but colonies were sent to a few plantations, among them the Hawaiian Agricultural Company. In 1918, when samples of infested cane leaves were received from that plantation for determination of the percentage of parasitism of the leafhopper eggs, *Paranagrus* issued abundantly from the material from their Wood Valley fields. These were 29 per cent males, which was a much higher proportion of males than we had known with *optabilis,* indicating that the Formosan *Paranagrus* had become established there. No further attention has been given it, however.

Paranagrus perforator Perkins (35, p. 199)

This egg parasite was described from Fiji, where it attacked leafhopper eggs laid in thick stems of grass, and was presumably introduced from there at the time

Ootetrastichus beatus Perkins was introduced, but detailed records were not made at the time. It became established, but not to any great extent and was recovered a few times. It had a preference for the leafhopper eggs that were placed in upper exposed internodes of the cane stalk. It was bred from eggs of *Aloha ipomoeae* Kirkaldy, a leafhopper on morning glory vines, in Makiki Valley near Honolulu, March 2, 1906. There appears to be no record of it since then. It is similar to *Paranagrus optabilis,* the chief distinction being the elongate ovipositor which extends beyond the apex of the abdomen for a length equal to all of the joints of the hind tarsi.

Anagrus frequens Perkins (35, p. 198)

This mymarid was the first to become established of the egg parasites introduced from Queensland in 1904, and became very abundant for a time after becoming widely distributed and dispersed. It finally almost entirely disappeared from the cane fields after *Paranagrus optabilis* became prevalent. It is smaller than *Paranagrus,* distinguished from it by antennal and other characters. The female parasitized more particularly leafhopper eggs that were placed in the blade of the leaf rather than in the midrib. On maturing, the adult *Anagrus* gnaws a hole through the epidermis of the leaf to make its exit. Often the holes were seen in clusters, indicating that a parasite had issued from each leafhopper egg in the cluster. When most abundant, 100 and more of these exit holes could be counted per leaf. This parasite parasitizes the eggs of the corn leafhopper to a considerable extent, and is thus still extant, but for some time now has been rarely seen in the cane fields.

Ootetrastichus beatus Perkins (35, p. 263)

This tetrastichine egg parasite was discovered destroying the eggs of the sugar cane leafhopper throughout Australia and Fiji. It was introduced from Fiji by Koebele early in 1905. This is a larger insect than the mymarids previously discussed. It oviposits in one egg of the leafhopper egg cluster. When the developing parasite larva has finished eating the contents of this one leafhopper egg it proceeds to eat the other eggs in the same cluster, thus the adult varies in size according to the number of leafhopper eggs its larva has had available for food. The full-fed larva has a tendency to burrow into the leaf tissue a little to one side for a pupal chamber. When the adult is formed, it gnaws a round hole through the upper surface of the leaf to make its escape. This exit hole is larger than that made by *Anagrus frequens,* and can also be distinguished from the latter as there is only one exit hole from a leafhopper egg puncture, whereas with *Anagrus* there is a cluster of smaller holes per egg puncture. Breeding is almost entirely parthenogenetic, a male being rarely seen. The length of its life cycle is about twice that of *Paranagrus,* being about 40 days, which is lengthened in cooler seasons or cooler regions. The adult is pale yellow or greenish yellow with a few dark markings on the thorax. Length variable, 1 mm. more or less (Fig. 7).

This parasite soon became established in the leafhopper-infested cane at the Experiment Station grounds in Honolulu, then it was distributed generally to the

plantations during 1906 in cuttings of midribs containing parasitized leafhopper eggs, these being sent out in wooden box cages to be suspended in a sheltered place in a cane field where the parasites that issued could find plenty of leafhopper eggs in which to breed. Many colonies were thus distributed. Apparently the first recovery on a plantation was at Olowalu, Maui, August 1906. In the summer of 1907, it was found to have become established on nearly all of the plantations and quite generally spread; on many of the plantations it was reported to be present wherever leafhopper eggs could be found. On a few of the plantations on the island of Hawaii it was not recovered until 1908. By this time it had become very abundant

Fig. 7. *Ootetrastichus beatus.*
(Courtesy of Territorial Board of Agriculture and Forestry.)

nearly everywhere, and often seemed to be doing more than *Paranagrus* in checking the leafhopper. It interfered somewhat with the effectiveness of *Paranagrus* for when its larva ate all leafhopper eggs of a cluster it no doubt often ate some eggs which were parasitized by *Paranagrus*. Its abundance could readily be determined by counting the exit holes in a leaf. It was common to find as many as 20 of these holes in a leaf, and counts were made of larger numbers. The highest count recorded was 79 exit holes in one leaf. As the average number of leafhopper eggs per cluster was over 4, the 79 parasites in developing would have destroyed over 316 leafhopper eggs. In recent years, the leafhopper itself being scarce, *Ootetrastichus beatus* is seldom seen.

Ootetrastichus formosanus Timberlake (55, p. 558)

This parasite was found by Dr. Muir parasitizing eggs of a leafhopper in cane leaves in Formosa. There are several species of leafhoppers on sugar cane in Formosa, and it is not recorded just which species was the host of this parasite. Dr. Muir brought a quantity of midribs upon his return to Honolulu in February 1916. From these midribs about 20 females and a few males of *Ootetrastichus* issued. They were placed in breeding cages where they reproduced on the eggs of the sugar cane leafhopper and, after a few generations, became numerous enough for liberation in cane fields. Multiplication of the parasite was carried on in breeding cages in the field at the Experiment Station during 1916 and 1917, and it was distributed in large numbers to the sugar plantations on the different Islands. During the latter

half of 1917 (June to December) it was found established in fields of six plantations on Oahu, Maui and Hawaii. In 1918 it was recovered on 23 additional plantations on Oahu, Kauai and Hawaii. On some of these plantations it was found to be very abundant and colonies were obtained from these fields for further distribution to other plantations. Finally, in 1919, it was recovered from 7 additional plantations, which indicated nearly complete establishment throughout the plantation districts. It soon became so abundant as to appear more effective than *Ootetrastichus beatus.*

Fig. 8. *Ootetrastichus formosanus,* female.

At the Waipio substation in May 1918, as high as 37 per cent of the leafhopper eggs were found to be parasitized by this parasite, which was a higher rate than by the other egg parasites at the same place and time. Conditions were found similar in several other localities. In later years when the leafhopper became universally scarce, *formosanus* was found oftener than *beatus.*

Fig. 9. *Ootetrastichus formosanus,* male.

Ootetrastichus formosanus is of darker color than *beatus.* The female (Fig. 8) is about 1.25 mm., varying with the number of leafhopper eggs in the egg cluster which the larva had the opportunity of eating. The thorax and hind part of the abdomen are metallic greenish, the basal part of the abdomen yellowish. The males (Fig. 9) are smaller and paler than the females and are usually about as many in number, or more. They are readily distinguished by the greatly enlarged basal joint of the antenna. In breeding experiments the life cycle (egg to maturity) was found

to be—egg and larva about three weeks, pupa about ten days—31 days with a minimum of 24 days, varying between that and two months. The adults were found to live as long as one to two months. In two experiments as to fecundity 39 and 95 respectively were produced from single females. In both cases the male progeny outnumbered the female.

Haplogonatopus vitiensis Perkins (35, p. 488)

This dryinid was first bred from a delphacid on a grass, *Zoysia pungens,* in Fiji, by Mr. Koebele in March 1905. A single female issued from a cage received March 7, 1906, from Fiji, sent by Dr. Muir in an attempt to introduce a stylopid parasite on the leafhopper. This female was placed in a cage with young leafhoppers which it instantly seized and apparently parasitized; thus, breeding of the parasite was started. Multiplication was slow, and only a few small colonies were distributed from July 1906 to August 1907, to a few of the plantations on Oahu and Hawaii. From these colonies the parasite became established so that it was recovered in a few places in 1908 and soon became quite common in some regions. Later on, it became widely spread, and was recovered also from plantations on Kauai and Maui. For a time it was a factor in reducing the leafhopper pest, but by about 1918 it became so scarce as to be seldom seen. This was partially due to the diminished numbers of the leafhoppers, but for the most part was due to the work of hyperparasites on it. As an example of the prevalence of the hyperparasites, at Hilo Sugar Company 11 cocoons of *Haplogonatopus vitiensis* were collected on cane leaves February 27, 1919. Hyperparasites issued from all of them. There were: 4 *Echthrogonatopus hawaiiensis,* 24 *Helegonatopus pseudophanes* and 2 *Saronotum americanum.* A few years earlier the conditions were the same at the Experiment Station grounds in Honolulu. Of 9 cocoons collected March 7, 1913, hyperparasites issued from all of them: 1 *Saronotum australiae* and 28 *Helegonatopus pseudophanes.* For several years past *vitiensis* has been seldom seen. The latest collected specimens in our cabinets were from the Kailua substation in 1929 and 1931. In 1931 when there was an outbreak of taro leafhopper in the Waianae district, *vitiensis* was found more abundant on this leafhopper than it had been for several years. (It was again recovered on cane leafhoppers at Kailua in January 1936.)

Only the female of this parasite is known, hence, breeding is parthenogenetic. The adult is always wingless; brown to brownish-black in color and about 3 mm. long. Usually it is the young leafhoppers which are attacked, but occasionally the adult leafhopper is parasitized. This is fortunate as it helped in dispersal, for these parasitized adult leafhoppers could fly to other regions before their death. As with other dryinids the larva feeds externally at the base of the abdomen, appearing like a wart on the body. With this species it is pale, about the color of the body of the leafhopper instead of being black as in the Fairchild parasite and the Chinese dryinid. When the parasite larva becomes fully grown it withdraws and leaves the empty leafhopper skin in order to spin a white oval cocoon on a cane leaf or stalk. The adult issues from the cocoon in about 2 weeks.

Pseudogonatopus hospes Perkins, The Chinese Dryinid (37, pp. 12-13)

This large black dryinid parasite of the sugar cane leafhopper was discovered by Dr. Muir at Wei Chou, about 120 miles up the East River from Canton, China, in

September 1906, where it parasitized a species of leafhopper (*Perkinsiella sinensis* Kirkaldy) on sugar cane. These leafhoppers were very scarce there, and only a very few were found parasitized by this dryinid. These were taken to Macao, China, where they were bred on leafhoppers in cages on sugar cane growing in tubs, until they had increased in sufficient numbers to forward to Honolulu. Shipments of cocoons of the parasite were received December 30, 1906, January 17 and February 19, 1907.

Fig. 10. *Pseudogonatopus hospes,* female.

Fig. 11. *Pseudogonatopus hospes,* larva on leafhopper.

The adult parasites issuing from these cocoons were retained for breeding at the Experiment Station. They increased so slowly that it was not until June 1907 that the first colony was sent out. Other colonies were sent out for liberation during July and August. These were mostly to the plantations of Oahu, but a few colonies were sent to plantations on the other Islands also.

At best, only small colonies were liberated in any place, and it was thought later that this parasite had failed to become established for, during several years, none was observed. The first recovery was that of a single female found at the Waipio substation, Oahu, March 24, 1916. In April it was collected on the plantation of Oahu Sugar Company, Ltd., and in May three adult leafhoppers parasitized by this dryinid were collected on the same plantation. In June of the same year it was noticed quite commonly in the cane at the Experiment Station grounds in Honolulu.

During 1917 recovery of the parasite was made at Ewa Plantation and Honolulu Plantation on Oahu; Makee Sugar Company, the Koloa Sugar Company, Kekaha Sugar Company, Ltd., and Waimea Sugar Mill Company, Ltd., on Kauai; Pioneer Mill Company, Ltd., Wailuku Sugar Company, and Hawaiian Commercial and Sugar Company, Ltd., on Maui; Hawi Mill and Plantation Company on Hawaii.

During 1918 it was recovered at Kahuku Plantation Company, Oahu; Kaeleku Sugar Company, Ltd., Maui; Olaa Sugar Company, Ltd., and Hawaiian Agricultural Company, Hawaii.

During 1919 it was recovered at Waialua Agricultural Company, Ltd., Oahu, and Onomea Sugar Company, Hawaii. Thus, it had become generally spread throughout the sugar plantation districts. In 1929 it was found to have reached Molokai by itself. It never became very abundant in the cane fields, ordinarily not more than

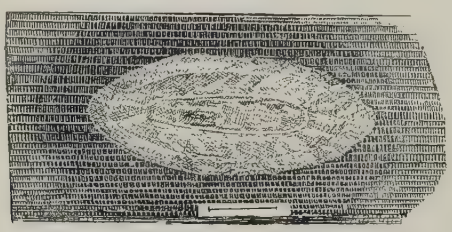

Fig. 12. *Pseudogonatopus hospes,* cocoon on leaf.

1 per cent of the adult leafhoppers would be found parasitized. The highest records taken were: 9.21 per cent on one occasion at Ewa Plantation Company in 1918, and 13.31 per cent at the same plantation in 1919. Hyperparasites* were found at work, so that when the dryinid cocoons were collected in the field, hyperparasites issued from a large proportion of them. From counts taken at various times of cocoons collected in the field, 25 to 100 per cent were found to be affected by one or more of the hyperparasites. This of course prevented this parasite from reaching any important efficiency. However, it has persisted even to recent years and with the scarcity of leafhoppers. Wherever a few of the latter are to be found, there is also likely to be found an occasional parasitized leafhopper, or an adult or cocoon of the parasite.

This dryinid attacks the adult leafhopper (Fig. 10). Only rarely is an im-

* *Helegonatopus pseudophanes* Perkins, *Saronotum americanum* Perkins, *Ceraphron abnormis* Perkins and *Paraphelinus xiphidii* Perkins.

mature leafhopper found parasitized by it. In this respect it differs from the Fairchild parasite (*Echthrodelphax fairchildii*) and the Fiji dryinid (*Haplogonatopus vitiensis*), both of which attack the immature stages of the leafhopper and only rarely an adult.

In parasitizing a leafhopper, the parasite catches and holds the leafhopper with her forelegs, which are especially adapted for this purpose (see Fig. 10), while she inserts the egg in the dorsal part of the abdomen. Having accomplished this, the leafhopper is released and it goes on about its usual life while the parasite develops on its back, resembling a black wart (Fig. 11). When the parasite larva becomes full-grown the leafhopper dies, and the parasite larva spins a white, oval, flat cocoon on a leaf (Fig. 12) or on the sugar cane stalk itself. The larva obtains its growth in one to two weeks. About three or four weeks are spent in the cocoon before the emergence of the adult. Thus, the life cycle is four to six weeks which is approximately about the same as that of the leafhopper.

In the laboratory a female dryinid lived 37 days and parasitized 153 leafhoppers, indicating the value of the parasite if its increase were not checked by the hyperparasites. The sexes are about equal in numbers, the male being winged while the female is always wingless (Fig. 10), although in one lot of 45 reared in the insectary there were 16 females and 29 males. In the field the female was more often observed. She would be greatly handicapped in accomplishing dispersal if it were not for the fact that it is the adult leafhoppers which she parasitizes. They have been found established early in newly planted fields at some distance, where they could not have migrated except by means of parasitized leafhoppers migrating by flight to the place before they were killed by the parasite larvae which they were carrying.

Cyrtorhinus mundulus (Breddin) (1)

While in Queensland in 1920 in search of additional natural enemies for the sugar cane leafhopper, Dr. Muir discovered that the little mirid bug, *Cyrtorhinus mundulus,* had the habit of piercing and sucking leafhopper eggs, and was the most efficient control agent of that pest. Although belonging to a family of bugs which are chiefly plant feeders, it seemed never to suck plant tissues. A small colony of the bugs was brought to Honolulu, and later in the year larger consignments were obtained and sent from Fiji by C. E. Pemberton. The bug had previously been known by Dr. Muir in Fiji cane fields without his having learned its habits. Three consignments were received from Fiji in September, October, and November 1920, and consisted of adults and young in cages with growing cane and leafhoppers. Several hundreds of the bugs were received in this manner. Some were released in plantation fields infested with leafhoppers, others were used for breeding in cages; breeding was kept up for a year. From the breeding cages many hundreds of bugs were obtained for distribution to the regions where the leafhoppers were most abundant. The bug readily became established in these places and spread from them throughout the entire sugar cane areas and even reached Maui and Molokai

without assistance. The first recovery was at Olaa only a month after liberation (their eggs were found in leafhopper-infested cane leaves sent in for examination). During the following year (1921) a few scattering recoveries were made and it seemed doubtful if the bug were becoming established sufficiently to be of any im-

Fig. 13. *Cyrtorhinus mundulus,* adult.

portance. In March 1922, the bugs were found very abundant at Ewa Plantation, at Waialua and at Olaa. During the year it was found sparsely in many regions, and during 1923 was found to be generally distributed throughout all the cane regions. The leafhopper was now almost entirely reduced, this bug proving to be more efficient in destroying the leafhopper eggs than were the egg parasites. In fact, without doubt, *Cyrtorhinus* caused a reduction in the efficiency of the egg parasites for it

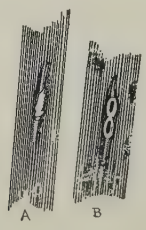

Fig. 14. *A.* An egg puncture of the leafhopper in cane leaf. *B.* The tips of two *Cyrtorhinus* eggs in an old leafhopper puncture.

Fig. 15. Midrib of cane leaf sectioned showing two *Cyrtorhinus* eggs in an old leafhopper puncture.

sucked leafhopper eggs regardless of whether they were already parasitized or not. In a few more years, with the scarcity of the leafhoppers, it became difficult to find

the egg parasites in the fields or parasitized leafhopper eggs. At this time (from 1923 on) the control of the leafhopper was considered to be complete, having finally reached this condition through the introduction and establishment of the *Cyrtorhinus,* which had increased to great abundance wherever there were leafhopper eggs. As outbreaks of leafhoppers were reduced by the *Cyrtorhinus,* the latter disappeared also, to appear again and increase to abundance wherever any new outbreaks of leafhopper occurred. It was considered by the entomologists (63) that if this bug had been the first to be introduced, it would by itself have been sufficient for the control of the leafhopper. Dr. Williams (63, pp. 103-104) states:

> The adult Cyrtorhinus [Fig. 13] is about 3 millimeters long; the general color is black, with the body in part (beneath the wings) reddish in the males and in all young adults, the legs and the base of the antennae are pale and the light smoky wings have a broad whitish front border. It seeks the eggs of the leafhopper and sucks them through a minute puncture which it makes with its slender beak. Wary and exceedingly active, it is usually approachable only with caution, otherwise it will dodge behind a leaf or stem or make a hasty flight to the next plant. The eggs [Figs. 14, 15] are inserted into small crevices in the cane leaf, a leafhopper egg-slit being frequently chosen; they are of shorter and stouter form than those of the leafhopper and occur singly or in very small groups. Rather close scrutiny is required for their discovery, when they may be recognized, where they are exposed, flush with the surface of the leaf, as rather evenly oval white discs or caps, the center of which is sunken and dark giving them a ring-like appearance in contrast to the irregularly protruding, waxy covering that protects the tips of the leafhopper eggs. [The eggs are white, becoming bright red before hatching.] The young Cyrtorhinus are rather short, and bright red and suggest somewhat red spiders or mites of the genus Trombidium. . . .

Their favorite habitat is within the spindle of the cane plant and when very numerous they were also found among the bristles of the leafsheath. Under favorable conditions *Cyrtorhinus* may produce ten generations per year.

Natural Enemies Which Were Already Present in Hawaii

In the years when the leafhopper infestation was at its maximum, it furnished an abundant food supply for numerous insects already present in Hawaii, the most of which were predatory in nature, although a few were parasites. Some of these insects were native species inhabiting the forests in the vicinity of cane fields, in which case they migrated into the cane fields where their food was plentiful, and they themselves increased to greater numbers than ever existed in their natural habitat. Several species of spiders, too, increased greatly in cane fields where unlimited supplies of food were found when leafhopper infestations prevailed.

Taken altogether, these had an appreciable effect on the reduction of the leafhoppers, and should be given ample credit for their part in the final results. Some account of these insects is given in various publications and by different entomologists; Perkins, Kirkaldy, Terry, Swezey, Muir, and Williams.

Echthrodelphax fairchildii Perkins (32, p. 37)

This dryinid (Plate 1) was discovered in 1903 parasitizing cane leafhoppers on Kauai, by Geo. H. Fairchild for whom it is named. Dr. Perkins considered it to be

a native species which had normally attacked native leafhoppers, but had transferred its attention to the cane leafhopper when the latter became abundant and furnished a great deal of host material for it. Many thousands of the parasites were reared in Honolulu during 1903 and 1904 and distributed to the plantations of the other Islands. It readily became established and common and was considered a help towards the reduction of the cane leafhopper before any of the egg parasites were introduced from Australia. It practically disappeared a few years later, and has not been seen for over 20 years. There are no specimens in our cabinets of a date more recent than 1905.

Both sexes are winged; the male is black and smaller than the female; the female black with yellow markings, and is 2.5 mm. long. Only the young leafhoppers are parasitized by this dryinid. The method of attack, etc., is given in detail by Dr. Perkins (35, pp. 7-10) as follows:

When in 1903 for the purpose of distribution in the canefields many hundreds of *Echthrodelphax* were kept in a cage with glass sides and large enough to contain a fair-sized growing plant of sugar cane, on which large flocks of the larvae of the cane leaf-hopper were feeding, the habits of the parasite could be studied to great advantage. By having a cage thus well stocked with the parasites, one can insure the fact that at almost any time individuals may be seen in the act of catching their prey. In such a cage, on one occasion, I counted over thirty parasites on a single cane stem each one simultaneously engaged in stinging the young hopper it had seized. When the hoppers were excreting an abundance of honey-dew, the parasites fed freely on this, but if not, some sweet liquid was supplied in place of it. Without liquid food, in a hot locality the parasites die very quickly, and the cage was freely sprinkled with water each day to advantage. Pairing of the sexes is of short duration and after copulation the male frequently never moves again, and in general dies very quickly. To watch the female parasite stalking, catching and stinging its prey, is a most interesting sight. The prey is sought on foot, for while most of the Dryinidae are most active and rapid runners, they are but poor performers on the wing. In most of the winged forms, these organs are unduly short and in *Echthrodelphax* serve hardly more than to transport it from one cane plant to another as occasion demands. As soon as the parasite becomes aware of the presence of its prey, it usually comes to a standstill, while still at a short distance; it assumes a rigid attitude comparable with that of a dog pointing game; the antennae are laid back behind the head; frequently it sidles round the hopper to gain a more advantageous position for the attack. The hoppers often show manifest uneasiness on the approach of the parasite and they hasten to remove themselves to a distance, as the latter comes to a point. In this case they are again followed up, and the performance may be repeated several times. In some cases through too great deliberation in attack the prey is entirely lost, as it moves away into concealment and the parasite fails to trace it up. Deliberate as it often is in making the attack, yet, when made, the stroke is marvelously rapid. So quickly indeed are the front legs thrown out and withdrawn that the hopper, which just now was at a distance, in an instant appears contiguous to the parasite, as if attracted by some unseen force. One pair of pincers usually grips the neck of the prey the other frequently clasps the pair of hind legs in the neighborhood of their long jumping spurs, or the abdomen towards the apex. If the hopper is unusually large and strong compared with its enemy, it not rarely manages to make its leap, and both fall to the ground together. Never however was the latter seen to relinquish its hold on the former. Its prey firmly secured and frequently held more or less crosswise to itself, the parasite now curls round the abdomen and thrusts its sting into the side of the hopper, beneath one of the wing lobes in the case of *Echthrodelphax*, and in various other positions in the case of other parasites, and the egg is deposited. The laying of the egg is again a very deliberate undertaking and the sting may remain inserted for a couple of minutes or more. Finally the sting is withdrawn, the front leg that grasps the hopper's neck is extended, the chelae or pincers fly open and the hopper is sometimes roughly jerked to a distance, sometimes more gently deposited on the plant. While grasping the hopper and in-

serting the sting, the parasite has been seen in some cases to freely use its mandibles on the neck in process of malaxation. After the operation, the victim usually appears weak and dazed, sometimes even lying inert on the ground, but sooner or later and sometimes very quickly, it recovers and starts feeding as if nothing had happened. Occasionally after capture, the prey is released without being stung, and it is probable that hoppers so released have already been stung by an earlier captor. Under unnatural conditions, such as in the confinement of a small jar or glass tube, and probably under pressure of hunger, the hoppers are frequently killed outright, and to some extent devoured. The position of insertion of the sting is apparently not always the same, this being sometimes inserted beneath the wing-lobe, and sometimes in the ventral side of the body, but the larval sac in either case appears beneath the wing-lobe. After the egg has been deposited, it is not for some time that the characteristic larval sac becomes evident externally. In the case of *Echthrodelphax*, I could distinguish the larval sac, having the appearance of a minute transparent vesicle, at the end of four days with the naked eye. In the case of a California species of *Haplogonatopus*, the period was not less than a week. On one occasion three cane leaf-hoppers were placed in a large glass jar with the *Haplogonatopus*, and two of them were seen to be quickly seized and stung. The next day the parasite was removed to another cage. At the end of six days, when the hoppers were examined, no sign of the larval parasite was noted, even with the aid of a weak lens, and it was supposed that they were unaffected. However on the ninth day, when they were again examined, the parasitic larvae were of considerable size, and obvious to the naked eye. The third hopper of the above produced no parasite and probably was not stung. As soon as the larval sac becomes visible, it is usually but a short time, a few days or a week before the larva becomes mature. The length of time no doubt varies somewhat according to the species, and according to climatic conditions.

The larva of the *Echthrodelphax fairchildii* while still attached to the hopper, appears as a small, nearly circular, impressed, black object, adherent to the young leaf-hopper. The latter seems hardly to be inconvenienced by the parasite, remaining as active and plump as the non-parasitized individuals. It is always the immature hopper that is attacked and a single hopper may sustain one or two parasites. They are generally fixed beneath the lobes, which develop into the tegmina or upper wings, one on each side of the body, if two be present; they are, however, sometimes found beneath the true wings.

After a time, however, (always shortly before the full growth of the parasitic larva) the hopper becomes sluggish and then entirely stationary. This may happen either shortly before or not till some time after the black shell-like covering or larval sac of the parasite splits by a longitudinal (mediodorsal) fissure and exposes the back of the white maggot within. This torpidity of the leaf-hopper and the splitting of the covering of the parasite is the outward sign of a change of habits in the latter (being coincident with a moult and change of form of the parasite). From this time until the hopper dies and the maggot finally quits hold of its prey the sight as examined under a lens forms one of the most repulsive sights that natural history can afford.

Soon after the splitting of the black covering and the exposure of the white maggot, a conspicuous change takes place in the color of the latter, it becoming pink or reddish. The maggot, which has hitherto fed delicately without doing any vital injury to its host, now proceeds to ingest the contents of the hopper in an indiscriminate manner, and the change in color is clearly due to this. If removed at this time from the hopper it is seen to have very mobile and hard (chitinized) mouth parts, while the thin and collapsed black covering still adheres some distance behind the head. Growth is extremely rapid and the simultaneous shrinking of the hopper, as its contents are absorbed by the parasite, enhances this effect. Thus when the splitting of the black covering takes place the hopper may be three or four times the size of the parasite, when the latter is full fed the proportions may be exactly reversed. The removal of the contents of the hopper can be easily seen through parts of the cuticle. Generally early in the proceedings the soft contents of one or both eyes and of the head are seen to be in rapid motion, like a boiling fluid, suddenly all the pigment is removed from one eye (usually the one on the opposite side to the parasite) and it becomes an opaque white spot, then the other is often similarly destroyed, or sometimes both more or less simultaneously.

Finally the maggot, when it has finished feeding, withdraws its head, and may then sometimes be seen busily engaged in applying sticky matter from its mouth to its body. Its surface is strongly adhesive and when it quits its prey, it is able (though of course quite legless) to crawl freely over any surface, however smooth. Soon it spins a neat white cocoon, from which it emerges as an active winged insect in about 18 days.

There is another native species of the family Dryinidae, *Pseudogonatopus perkinsi* (Ashm.), which parasitizes several species of delphacid leafhoppers in the native forests of the Hawaiian Islands, but it was never found to attack the cane leafhopper.

Coelophora inaequalis (Fab.)

This lady beetle (Fig. 16) was introduced from Australia by Mr. Koebele, in 1894, as an aphis-feeder. It soon increased until it was generally spread and at the time of maximum leafhopper infestations was found to be nearly always present in leafhopper-infested cane fields and sometimes extremely numerous. Its larvae took to feeding on the young leafhoppers, especially at the moment of hatching, and became very efficient.

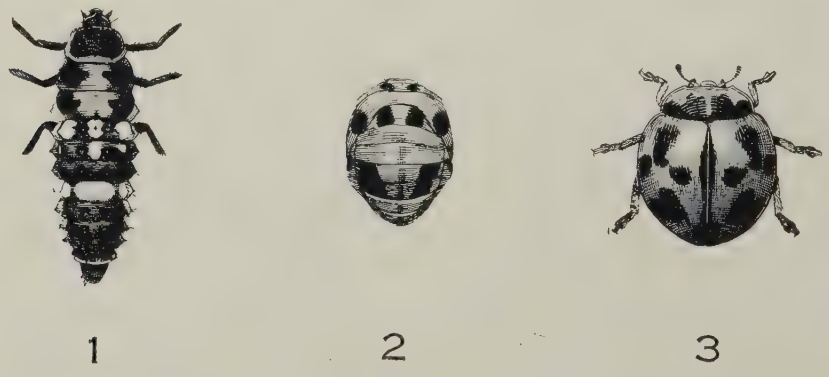

Fig. 16. Australian ladybeetle, *Coelophora inaequalis*.
1. Larva. 2. Pupa. 3. Adult.

The life cycle of this lady beetle is short, being 2 to 3 weeks under favorable circumstances and with plentiful food supply. The egg stage is 3-4 days, larval stage 8-9 days, pupal stage 3-4 days, totalling 14 to 17 days. Adults are notedly long-lived as with many lady beetles. The voracious nature of the larvae together with the short life cycle, by which a rapid increase in numbers takes place, make this a very valuable leafhopper enemy. The adults quickly found leafhopper outbreaks at their beginning, and could soon increase to efficient numbers. The fact that they fed primarily on aphis was a help toward their maintaining their existence in cane fields, as there were likely to be enough cane aphis infestations, generally distributed, so that the population of lady beetles could be maintained on one or the other and always be ready to migrate to new outbreaks.

At the present time this lady beetle is scarce in cane fields, as there are less outbreaks of cane aphis and numerous natural enemies check these soon enough to

prevent severe infestations, and the leafhoppers are so scarce that probably they are no longer of any importance as food for the larvae of this lady beetle. In gardens, this lady beetle is always to be found when aphis is present on any plants. They are especially noticeable on hibiscus hedges when infested with the cotton aphis.

A braconid parasite, *Dinocampus terminatus* (Nees), has occasionally been found attacking the adult of this lady beetle, but it is never numerous enough any more to be of importance in the effectiveness of the lady beetle.

Conocephalus saltator (Sauss.)

This is commonly known as the longhorned grasshopper. It was described by Mr. Swezey as *Xiphidium varipenne* (41, p. 216) on account of the variation in length of tegmina, but later was found to be of tropical American origin and is now known as *Conocephalus saltator*. It was known as an immigrant insect in Hawaii as early as 1895. In 1899, Dr. Perkins stated of it in the *Fauna Hawaiiensis*, "Only in and around Honolulu." It must have increased and spread rapidly soon thereafter for Mr. Swezey says of it in 1905, "At present very generally distributed, in fact, it might be said that they are everywhere, lowlands, valleys and mountains, gardens, pastures and cane fields." They became especially abundant in leafhopper-infested cane fields. As there was no evidence of their being injurious to the cane, particular study of their habits revealed that they were feeding extensively on the leafhoppers. They had the habit of lurking about the axils of the upper leaves, or the crown of the cane stalk just where the leafhoppers congregated in large numbers in the young cane, and it was easy for the grasshoppers to capture an abundance of their prey, especially the young leafhoppers. In cage experiments grasshoppers would scarcely eat any of the cane leaves, but would readily devour leafhoppers that were introduced. Freshly hatched grasshoppers starved to death in 5 to 6 days in the presence of tender grass and cane leaves, while those provided with leafhoppers were reared to maturity. Older grasshoppers do nibble the tips of cane leaves to a slight extent. They also feed on flowers of various kinds, as canna, lantana, ginger, morning-glory and many weeds. Sometimes this grasshopper has done considerable injury to rice by feeding on the heads when the growing rice grains were still soft.

The female (Plate 3) has a sword-like ovipositor by which she inserts her eggs behind the leafsheath on cane and in similar places on grasses, canna, or other plants. The eggs are 5 mm. long and are deposited in clusters of 2-15, side by side, with the anterior end outermost. They are white, turning green before hatching, which occurs in about 5 weeks. The young grasshoppers molt at intervals of 6-23 days during their growth, becoming mature on the sixth molt. This takes about 10 weeks or a total of about 15 weeks from egg to adult. It is not known how long an adult lives, but it is certain that one individual during its period of growth and then its mature period would consume many hundreds of leafhoppers, no doubt thousands of them. As there were swarms of all stages of the grasshoppers in cane fields when badly infested with leafhoppers, it is evident that these grasshoppers would be of great service in reducing the leafhoppers. Since the cane leafhopper has become scarce, this grasshopper is no longer abundant in cane fields, but is always to be found in grassy regions, where it undoubtedly finds insects to prey upon, but no

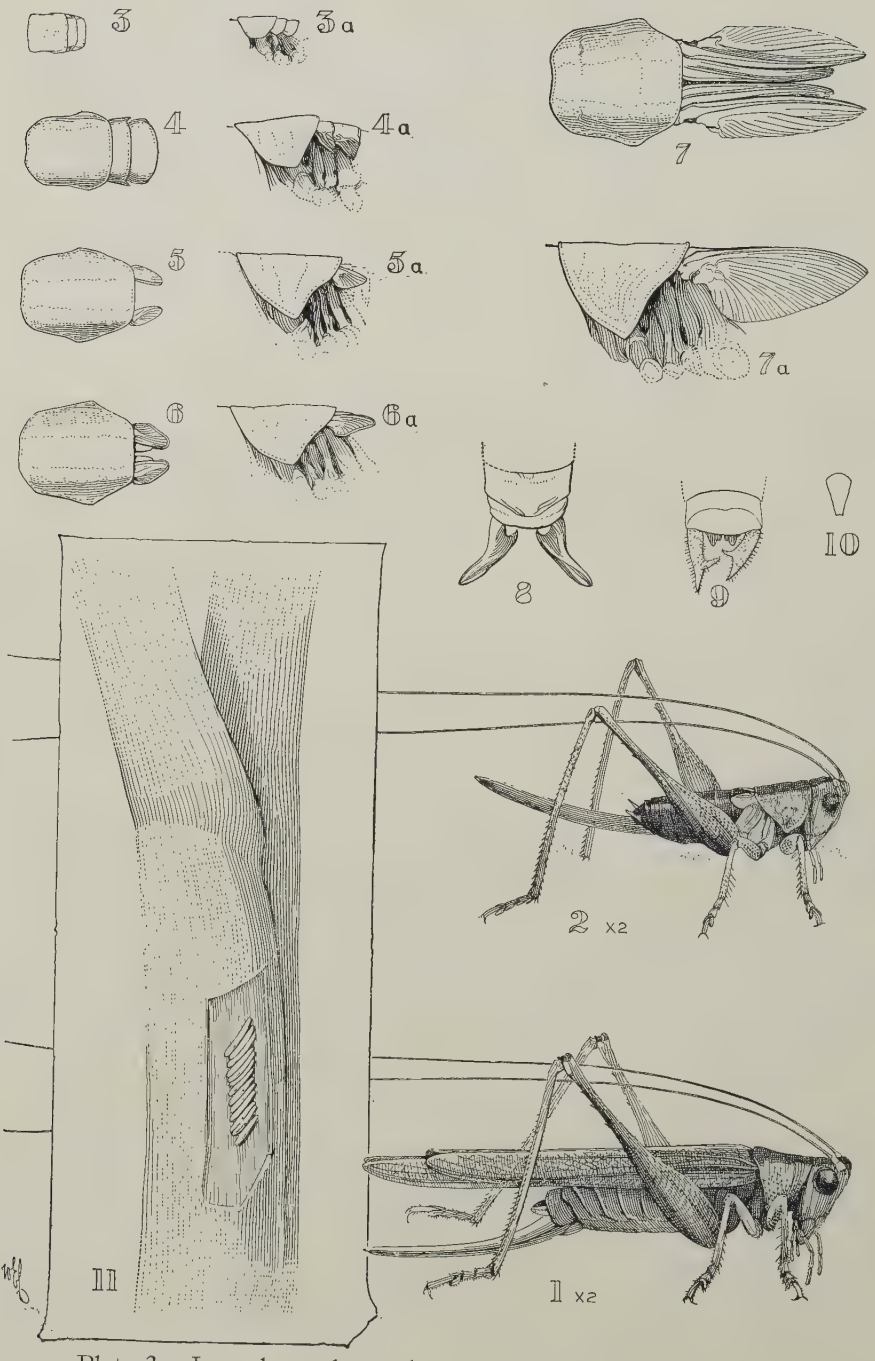

Plate 3. Long-horned grasshopper *(Conocephalus saltator)*.

1. Adult female.
2. Immature female.

3-7 and 3a-7a. Dorsal and lateral views of thorax to show development of wings.

8. Cerci of male.
9. Cerci of *C. fuscum*, a related species not found in Hawaii.
10. Fastigium (an area on top of head).
11. Eggs, natural size, showing location behind leafsheath of sugar cane. The tiny holes in several of them show where parasites have issued.

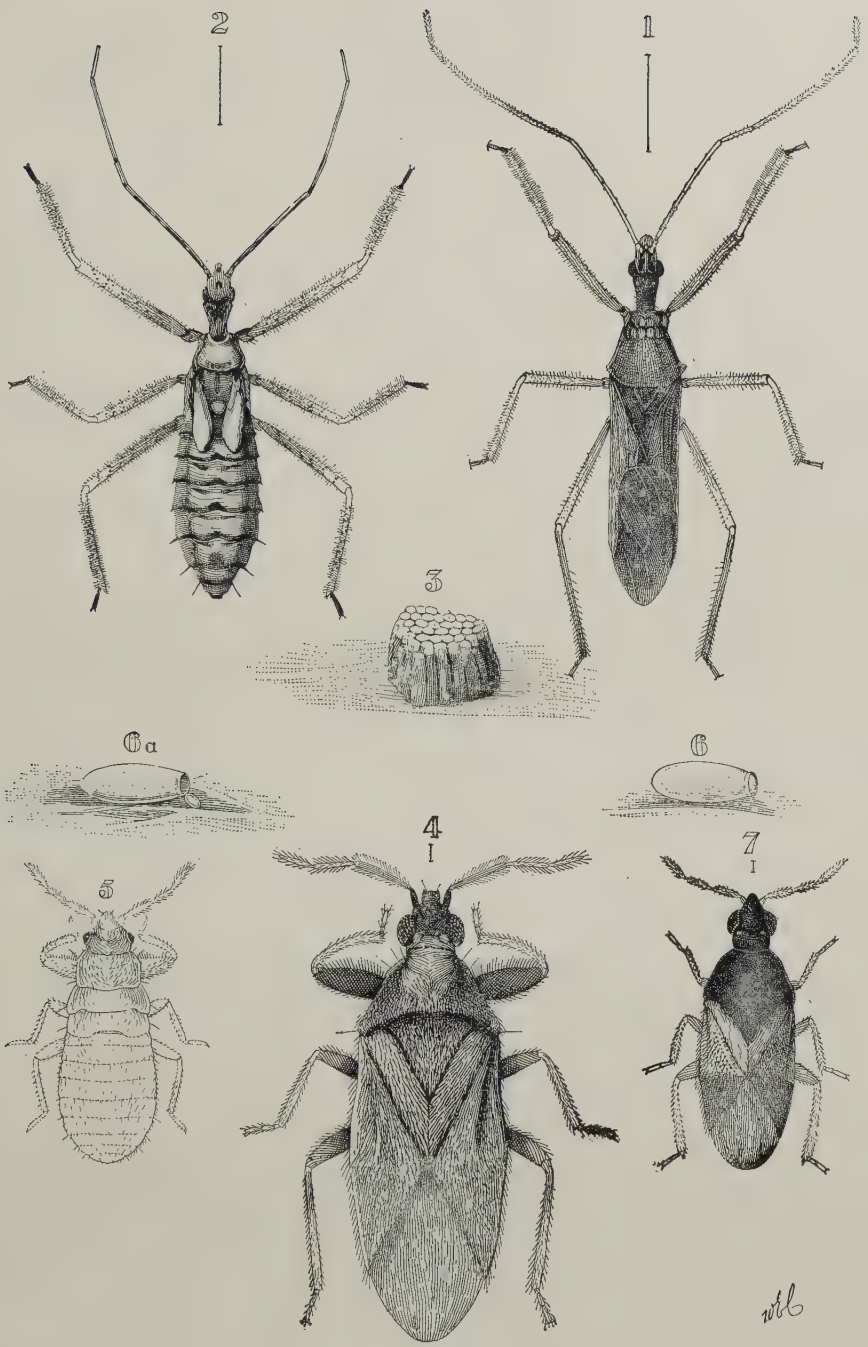

Plate 4. Predacious bugs.

1. *Zelus renardii,* adult, x 4.
2. *Zelus renardii,* nymph, x 4.
3. Egg cluster, x 5.
4. *Physopleurella mundulus,* x 20.
5. *Physopleurella mundulus,* nymph, x 20.

6 and 6a. *Physopleurella mundulus,* eggs, x 15.

7. *Triphleps persequens,* x 20.

recent observations have been made to determine which insects chiefly make up its present menu.

The eggs of this grasshopper were often found parasitized by a tiny aphelinine *Centrodora xiphidii* (Perkins) (35, p. 264) of which 9-14 would issue from one grasshopper egg. Sometimes every grasshopper egg in a cluster would be parasitized. The eggs turn black when parasitized. The life cycle of the parasite was found to be 20 to 31 days, which is shorter than the length of time it takes the egg to hatch. It is no doubt a considerable check on the grasshopper, yet the latter continues common or abundant in all grassy places.

Zelus renardii Kolenati

The assassin bug (Plate 4, Figs. 1-3) is an immigrant bug from the western United States, and was first known to be established in the Hawaiian Islands prior to 1897. It was described as *Zelus peregrinus* (7, p. 149) by Kirkaldy in 1902 and known under that name until 1907, since when it has been known as *renardii* the Mexican and Californian species. It feeds on many kinds of insects by piercing with its beak and sucking the fluid contents. On account of its indiscrimination in regard to prey, it is not wholly beneficial, for it destroys many beneficial insects as well as those which are pests. During the years when the cane leafhopper was at its maximum, this bug was generally common in the cane fields and destroyed large numbers of adult leafhoppers and nymphs.

In more recent years it is not so numerous and has been found feeding on a large variety of insects, many of them beneficial, and, hence, it may be that the assassin bug is more detrimental than useful. In a list of 30 species of insects upon which *Zelus renardii* has been found feeding, 12 are distinctly beneficial. In the following list they are marked with an asterisk, those which are distinctly injurious insects are marked with two asterisks.

Hymenoptera	**Apis mellifera* Linn.
	Tetramorium guineense (Fab.)
	**Odynerus threnodes* Perkins.
	**Odynerus nigripennis* (Holmg.)
	Xenocrabro distinctus (Sm.)
	Pison iridipennis Sm.
	**Scolia manilae* Ashm.
	Epyris extraneus Brid.
	***Diplazon laetatorius* (Fab.)
	**Nesopimpla naranyae* Ashm.
	**Heterospilus prosopidis* Vier.
	Microdus hawaiicola Ashm.
	**Telenomus nawai* Ashm.
Diptera	**Frontina archippivora* Will.
	**Ceromasia sphenophori* Vill.
	Chrysomyia megacephala (Fab.)
	Chrysomyia rufifacies (Macq.)
	Ophyra nigra (Wied.)
	Chrysosoma fraternum Van D.

Coleoptera	**Coelophora inaequalis* (Fab.)
	**Cryptolaemus montrouzieri* Muls.
	**Curinus coeruleus* (Muls.)
	Araecerus fasciculatus (De G.)
Hemiptera	*Zelus renardii* Kol.
	Nysius coenosulus Stal.
	**Cyrtorhinus mundulus* (Bred.)
	Teleonemia lantanae Dist.
	***Perkinsiella saccharicida* Kirk.
	***Peregrinus maidis* (Ashm.)
	***Siphanta acuta* (Walk.)

The eggs of *Zelus renardii* are cylindrical, a little more than 1 mm. in length. They are deposited on the surface of a leaf in columnar masses of 20 to 40 eggs. These egg masses are brown in color and covered with a sticky substance, the anterior ends of the eggs are whitish with a depression in the center and a raised fringe at the periphery. A captured female deposited 8 egg masses totalling 269 eggs, in 5 weeks, and died 4 days after depositing the last egg mass. Probably she had laid some eggs before being captured, so that her total egg production might have been considerably higher. The eggs hatch in 8 to 10 days, and the young bugs grow to maturity in 4 to 5 weeks, molting 5 times at intervals of 5 to 9 days. The young bugs used to find the concentrated colonies of young leafhoppers on the under side of cane leaves and live right among them, destroying large numbers of them while maturing.

Reduviolus capsiformis (Germar) (4)

Reduviolus blackburni (White) (60, p. 373)

These two predacious nabid bugs (Plate 5, Figs. 1-4) are generally distributed in grass lands throughout the Islands. They became very abundant in cane fields, the former especially in the lowlands, and the latter at somewhat higher elevations and were an important factor in leafhopper control when the pest was at its maximum. Of the two species, *capsiformis* is cosmopolitan and *blackburni* is a native bug. They and their young feed specially on the young leafhoppers and also on cane aphis and other small insects. They are much smaller in size than *Zelus,* but were probably proportionately efficient.

The eggs are inserted in a leaf, normally in the midrib. There may be several in an irregular row, near, but not in contact as the leafhopper eggs are. Eggs of *capsiformis* were found to hatch in 10 to 11 days, the nymphs grew to maturity in about 24 days after 5 molts of about 5-day intervals. A mymarid parasite was found attacking the eggs of this bug and thus checking its efficiency. This was *Polynema reduvioli* Perkins, (35, p. 196) related to other native species of *Polynema,* some of which are known to parasitize the eggs of native leafhoppers of the families Delphacidae and Cicadellidae.

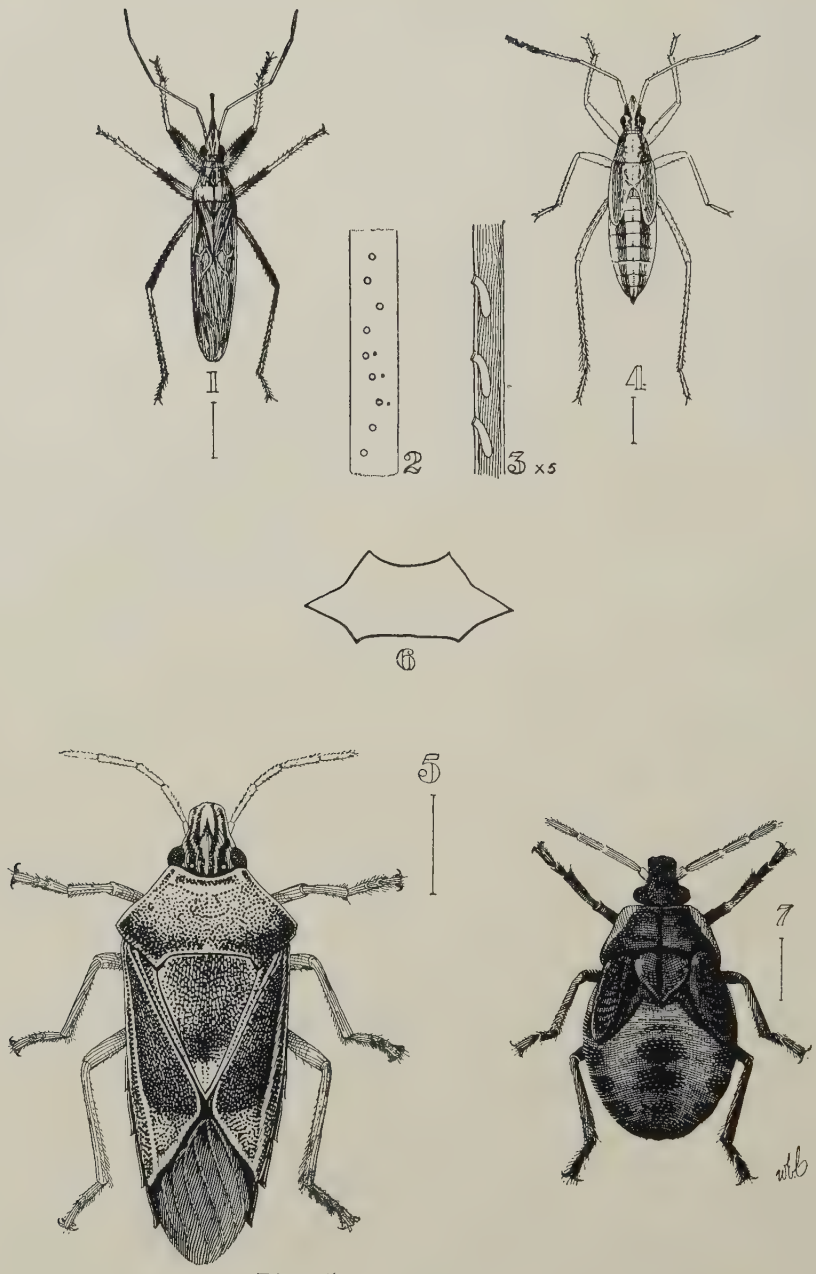

Plate 5. Predacious bugs.

1. *Reduviolus blackburni.*

2. *Reduviolus blackburni,* surface of leaf showing external appearance of eggs which are inserted; the tiny holes at the side of several are where parasites have emerged.

3. *R. blackburni,* section of leaf showing inserted eggs.

4. *R. blackburni,* nymph.

5. *Oechalia grisea.*

6. *Oechalia grisea,* prothorax of another specimen showing variation in the spines at posterior angles.

7. *O. grisea,* nymph.

All figures x 5.

Triphleps persequens White (59, p. 111)

Physopleurella mundulus (White) (59, p. 111)

These two small anthocorid bugs (Plate 4, Figs. 4-7) are more especially predacious on aphids, psocids and other small insects. They are considered as immigrants in Hawaii. They both became common and generally distributed in cane fields where they fed on young leafhoppers when this pest was at its maximum, however, due to their small size, they were not of much importance.

Oechalia grisea (Burm.) (2, p. 293)

This is a large native pentatomid bug (Plate 5, Figs. 5, 7) occurring in the Hawaiian forests on all the Islands. They are particularly predacious on caterpillars occurring on the foliage of the native trees. At the time of greatest prevalence of the cane leafhopper they were found in those cane fields of higher elevation adjacent to the forests, particularly on the island of Hawaii, and fed to some extent on the leafhoppers, as well as on the cane leafroller caterpillars where these occurred.

The eggs are deposited in clusters of 10 to 20 on the surface of leaves. They are nearly spherical, flattish at top and bottom, with a circle of 9 to 11 whitish, black-tipped capitate processes around the edge at the top, the portion within this row is neatly removed as a lid in hatching. The lower half of the egg is white, the upper half, pale bronzy-green with surface finely reticulate. The life cycle has not been studied, but during the lifetime of the nymphal stages and adult many insects are eaten. They have not been observed to feed on beneficial insects.

(In his recent study of the genus Oechalia in Hawaii, E. P. Van Duzee, of the California Academy of Sciences, finds that what we have long considered as *grisea* is really composed of several species.)

Chelisoches morio (Fab.) (3, p. 270)

Euborellia annulipes (Lucas) (15)

Of several earwigs occurring in cane fields, these two cosmopolitan species (Plate 6) have been known to feed extensively on leafhoppers when the latter were abundant. They are generally predacious, feeding on whatever insects they can find in the places that they are accustomed to frequent, under trash, stones, or under bark, etc., and on cane they lurk behind the leaf sheaths and in the spindles where they could readily capture the leafhoppers. Besides eating leafhoppers, the first species was found to eat many of the egg parasites also, thus somewhat offsetting the good that it did by eating leafhoppers.

The first species is black and provided with wings, the second species is brown and wingless. They are more common in wet regions than in dry areas. The eggs of *Chelisoches morio* are deposited in masses of from 40 to 60 eggs in some secluded place, often behind the leafsheath of cane and in similar situations on other plants. They are white, broadly oval, 1 mm. long by .75 mm. in diameter increasing to twice the bulk before hatching which occurs in about 5 or 6 days. The young are actively predacious, molt 4 times at intervals of 6 to 20 days and become mature in about 50 days.

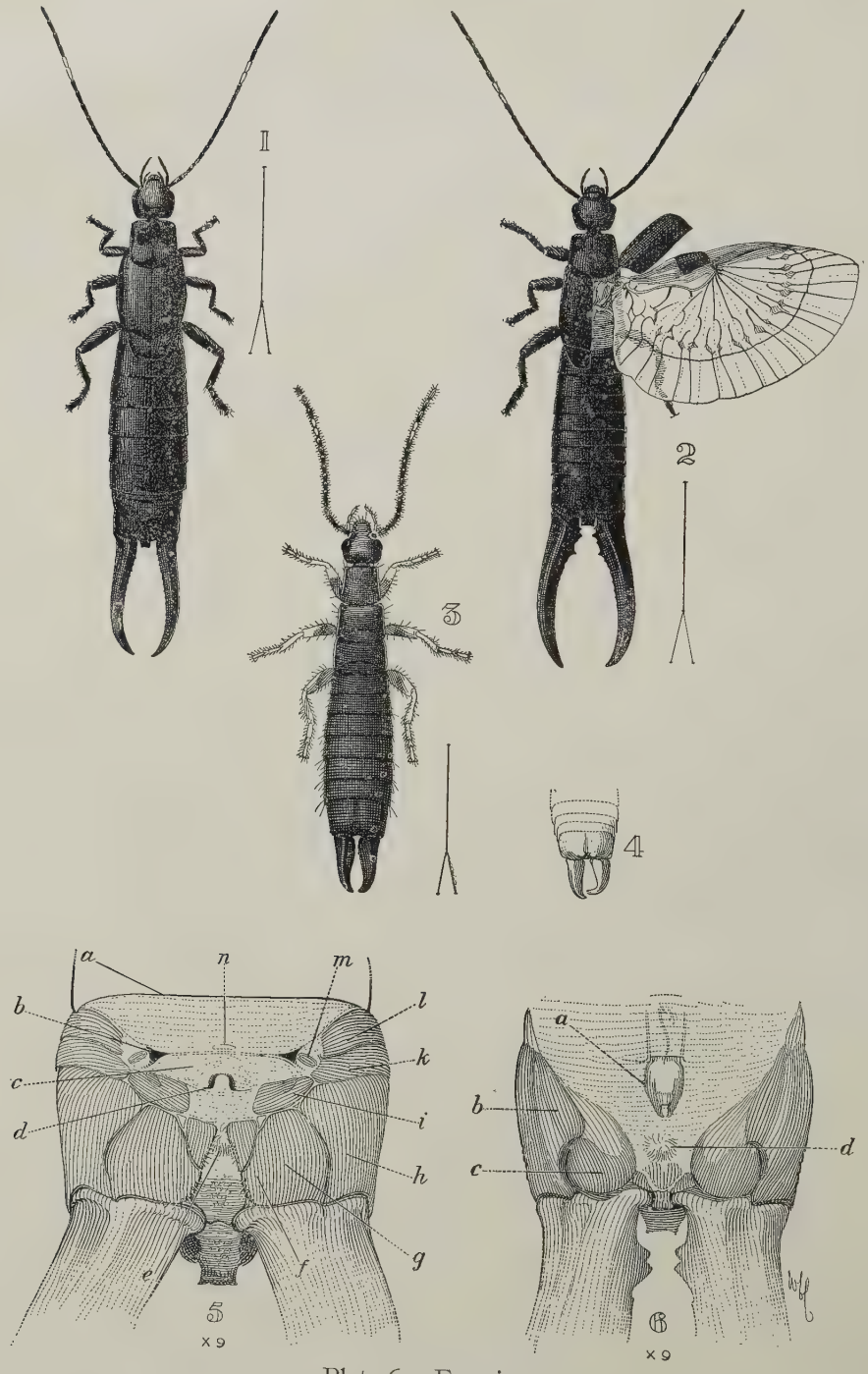

Plate 6. Earwigs.

1. *Chelisoches morio*, adult female.
2. *Chelisoches morio*, adult male.
3. *Euborellia annulipes*, adult female.
4. *Euborellia annulipes*, forceps of male.

5 and 6. Structure details of *C. morio* (irrelevant to the present purpose).

Chrysopa microphya McLachlan (16, p. 300)

This green lacewing fly (Fig. 17) is considered an immigrant in Hawaii, but it was described from Hawaii where it has been known for many years and is not yet known elsewhere. The larvae prey especially on aphids, scale insects, etc., but in the time of maximum infestation by leafhoppers they occurred in cane fields all over the Islands and fed chiefly on young leafhoppers.

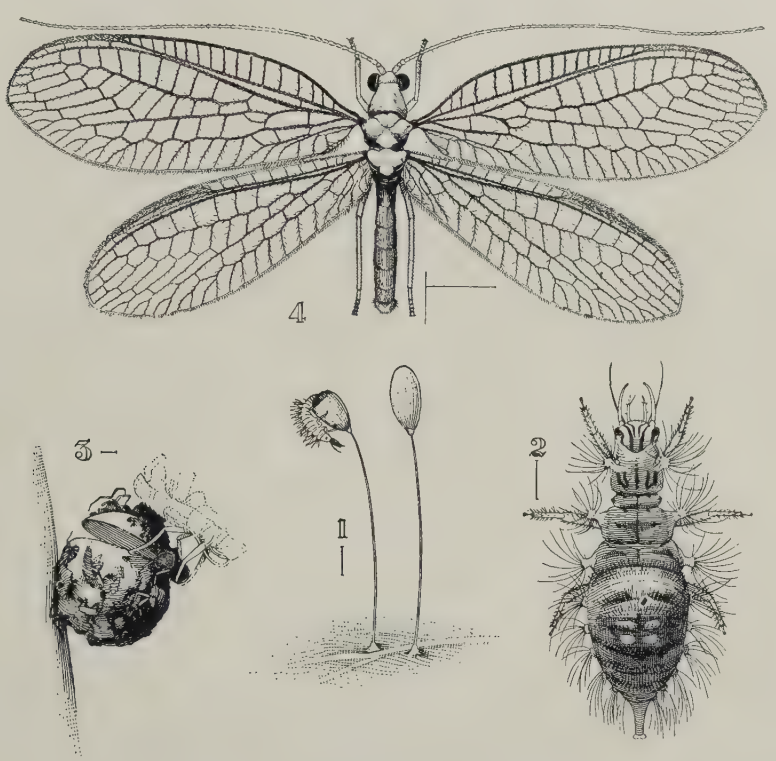

Fig. 17. Lacewing fly, *Chrysopa microphya.*

1. Egg and newly hatched larva.
2. Full-grown larva.
3. Cocoon and pupal skin.
4. Adult female.

The eggs are deposited on the under surface of a leaf, singly, or a few in a cluster, each elevated on a slender stalk several times the length of the egg. The larvae become full-fed in about 15 days, when each makes a dense, spherical, white cocoon from which the adult issues in about 10 days. As is common with many other species of *Chrysopa,* the larva of this one covers its back with the dry remains of insects from which it has sucked the fluid contents; the cocoon also is covered similarly. The cocoons are frequently parasitized by an ichneumonid, *Hemiteles tenellus* (Say). Recently another parasite has been reared from cocoons in Honolulu. It is *Isodromus axillaris* Timb. (54, p. 183) an immigrant from China. These parasites greatly check the good work of *Chrysopa.*

Anomalochrysa deceptor Perk. (29, p. 54)

Anomalochrysa gayi Perk. (29, p. 56)

Anomalochrysa raphidioides Perk. (29, p. 57)

Anomalochrysa proteus Perk. (29, p. 59)

These large species of endemic lacewing flies, occurring in the mountain forests, migrated into the upper cane fields adjacent to the forests on the island of Hawaii when their larvae found abundance of young leafhoppers for food.

The eggs of these species are laid on end directly on the surface of the leaf, not elevated on a stalk as are those of *Chrysopa microphya.* Their larvae are usually bright colored, some green, and others pinkish or yellow, and they do not carry debris or insect remains on their backs.

The cocoons are oval to spherical, of tough silken texture, and are probably sometimes parasitized by an ichneumonid, *Hemiteles tenellus* (Say), and sometimes by a eupelmid, *Eupelmus chrysopinus* Perkins. The eggs are also sometimes attacked by *Trichogramma minutum* Riley.

Since the leafhoppers became scarce, these lacewig flies are not seen in the cane fields.

Fig. 18. *Nesomimesa hawaiiensis,* a native wasp which sometimes preys on the leafhopper.

Fig. 19. *Nesomimesa hawaiiensis,* pupa.

Nesomimesa hawaiiensis Perk. (28, p. 11)

This native mimesid wasp (Figs. 18-20) lives in the forests on the island of Hawaii, where it preys on native species of leafhoppers, storing them in underground nests as food for the young wasps. It was found commonly in 1918 in some cane fields at higher elevations near forested regions where its behavior was observed by Dr. Williams (61). The female wasp captured adult leafhoppers from

the cane leaves one at a time, stung and paralyzed them and carried them to store in her nest. The nest (Fig. 20) is a burrow in an exposed earth bank. The main shaft extends inwards, inclining upwards at first, and eventually turns downward and gives off several branches, sometimes as many as 18, with a cell at the end of

Fig. 20. *Nesomimesa hawaiiensis,* nest in the ground.

each in which are stored the paralyzed leafhoppers. In each cell 3 to 16 leafhoppers are stored, a single egg being laid on the underside of one of the leafhoppers. The larva hatches in about 2 days, and devours its store of leafhoppers in about 6 days, then spins a silken cocoon in which it transforms to the adult wasp in about a month. The usefulness of this wasp is evident, since a nest of 12 cells was found to contain 65 leafhoppers, and besides there were cocoons in 3 cells and one or two other cells in which part of the leafhoppers had already been eaten. An estimation of 100 could readily be made for such a nest, representing the activities of a single, female wasp. It is not known how many nests she may produce in her lifetime. Only a few localities were benefited by this wasp.

Fig. 21. *Pipunculus* sp., a native fly that parasitizes leafhoppers.

Pipunculus juvator Perk. (35, p. 152)

Pipunculus terryi Perk. (35, p. 153)

Pipunculus hawaiiensis Perk. (35, p. 155)

These are native flies (Fig. 21) which normally parasitize native species of leafhoppers in the native forests. On the island of Hawaii, particularly, the first and

third species became very abundant in the cane fields during those years when the cane leafhopper was abundant. The second species was found in a cane field on the island of Kauai. Another species was occasionally found in cane fields on the island of Oahu.

The female fly captures a young leafhopper, preferably half-grown or less and while in flight, holding the leafhopper with her feet, oviposition takes place. The leafhopper is immediately dropped, and seems unhurt. The larva is of slow development within the young leafhopper, not reaching full growth until after the leafhopper has become mature. When parasitized by *Pipunculus,* adult leafhoppers may appear more sluggish and the abdomen is somewhat swollen. The full-grown *Pipunculus* maggot leaves the body of the leafhopper and forms its puparium on the ground in soil or beneath trash, sometimes they are found on or at the base of cane leaves. The egg and larval stage is about 40 days, and about a month is spent in the puparium, so that it is a rather long life cycle for a small fly. Only a small percentage of leafhoppers were found to be parasitized by *Pipunculus*—about 2 to 5 per cent—but in one instance 23 per cent of leafhoppers dissected were found to contain *Pipunculus* maggots (62). These flies are seldom seen in cane fields of late years when the leafhoppers are scarce.

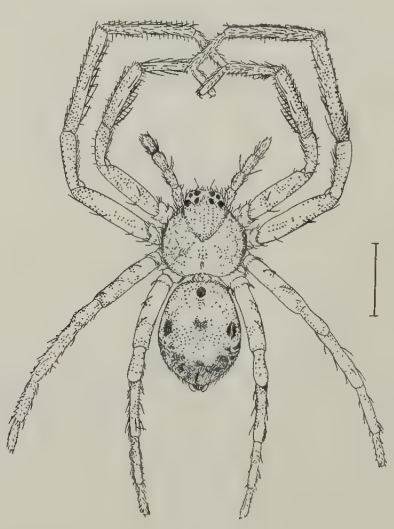

Fig. 22. *Pagiopalus atomarius,* a spider useful in destroying leafhoppers.

Spiders

Many species of spiders were attracted to the cane fields and increased to great abundance when there were severe infestations of leafhoppers. These spiders fed extensively upon both young and adult leafhoppers, but they also preyed on other insects which were abundant on account of the leafhopper infestations, some of which were beneficial in habits, so that the spiders were not entirely useful, although they probably were in the main more beneficial than harmful.

The two species of spiders which were considered of most importance are *Pagiopalus atomarius* Simon and *Tetragnatha mandibulata* Walck. (Figs. 22-23). The former is one of the hunting spiders and does not construct a web. Its presence in cane fields where leafhoppers were numerous was made evident by the conspicuous white, flat, circular egg cocoons which were placed on the surface of the cane leaves, sometimes 2 to 6 of them contiguous in a row along a midrib, and as many as 50 having been counted on a single leaf. At one time this spider was distributed artificially by taking cane leaves with the egg cocoons attached, from fields where abundant, and transferring to other fields where they were scarce or not present.

Tetragnatha spiders spun webs for capturing their prey, and there is no doubt that besides the leafhoppers many of the egg parasites and other beneficial insects were caught in their webs.

Heteropoda regia (Fab.), another of the hunting spiders, although best known as a house spider, also frequented cane fields and although the adult spiders preyed on such large insects as roaches and grasshoppers, the young spiders could feed on the leafhoppers when abundant. Another hunting spider recorded as feeding on leafhoppers was *Adrastidea nebulosa* Simon.

Fig. 23. *Tetragnatha mandibulata,* a spider useful in destroying leafhoppers.

Several species of jumping spiders also became numerous and utilized the leafhoppers for a part of their diet such as, *Plexippus paykulli* (Aud.), *Hasarius adansoni* (Aud.), *Bavia aericeps* (Sim.), and *Mollica microthalmus* (Koch.).

Enemies of Spiders

There are several species of wasps which store up spiders in the cells of their nests for the wasp larvae to feed on. The best known is the common mud-dauber *Sceliphron caementarium* (Drury). Others in Hawaii are *Pison hospes* Sm., *Pison iridipennis* Sm., *Pison argentatum* Schuck., *Trypoxylon bicolor* Sm., *Trypoxylon philippinensis* Ashm. and *Anoplius luctuosus* (Cress.). The larvae of two species of ichneumonids feed on spider eggs in their silken egg cocoons—*Arachnoleter swezeyi* Cush. and *Tromatobia rufopectus* (Cress.). The larvae of two species of flies of the family Drosophilidae feed similarly on certain spider eggs—*Titanochaeta ichneumon* Knab and an undetermined species.

Various cane field spiders are attacked by one or more of these enemies listed and thus their efficiency lessened. *Arachnoleter swezeyi* and *Tromatobia rufopectus* are in turn attacked by a parasite, *Pleurotropis wilderi* (How.), which issues in numbers from their cocoons. A parasite, *Eupelmus melanotarsus* Perkins, similarly issues from the puparia of the fly *Titanochaeta ichneumon,* mentioned above.

Fungus Diseases of the Leafhopper (39, pp. 54-55)

Entomophthora sp.

Sporotrichium sp.

Cordyceps

In the regions of greatest humidity there were times or seasons when one or more of these fungus diseases was particularly effective in killing off almost the entire leafhopper population in severe infestations. Probably the *Entomophthora* was the most effective and it was more prevalent on the plantations of the wetter districts on the island of Hawaii than elsewhere. The whitish, fungus-covered, dead leafhoppers would be seen in large numbers stuck to the surface of the cane leaves. This was not of regular occurrence but was very effective at times. Of late years with the scarcity of leafhoppers in cane fields, fungicized specimens are seldom seen.

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Appendix A

Distribution of Leafhoppers of the Genus *Perkinsiella*, Chiefly Sugar Cane Infesting Insects

(1) *P. saccharicida* Kirkaldy. The Entomologist, 36, p. 179, 1903. Hawaii, Australia, Federated Malay States, Formosa, South China; and Natal, Mauritius, Fiji (one specimen each).
(2) *P. vastatrix* (Breddin). Deutsch. Ent. Zeit., p. 107, 1896. Java, West Borneo, Amboina, Ceram, Papua, Philippines, Federated Malay States.

(3) *P. graminicida* Kirkaldy. Exp. Sta., H.S.P.A., Ent. Ser. Bul. 1, Pt. 9, p. 406, 1906. Queensland.
(4) *P. vitiensis* Kirkaldy. Exp. Sta., H.S.P.A., Ent. Ser. Bul. 1, Pt. 9, p. 406, 1906. Fiji, Samoa, Savage Id. or Niue.
(5) *P. sinensis* Kirkaldy. Exp. Sta., H.S.P.A., Ent. Ser. Bul. 3, p. 138, 1907. China, West Borneo, Japan.
(6) *P. pallidula* Muir. Exp. Sta., H.S.P.A., Ent. Ser. Bul. 9, p. 6, 1910. Borneo.
(7) *P. rattlei* Muir. Expt. Sta., H.S.P.A., Ent. Ser. Bul. 9, p. 6, 1910. Papua, New Caledonia.
(8) *P. bicoloris* Muir. Exp. Sta., H.S.P.A., Ent. Ser. Bul. 9, p. 7, 1910. Papua.
(9) *P. lalokensis* Muir. Exp. Sta., H.S.P.A., Ent. Ser. Bul. 9, p. 9, 1910. Papua.
(10) *P. variegata* Muir. Exp. Sta., H.S.P.A., Ent. Ser. Bul. 9, p. 8, 1910. Papua.
(11) *P. papuensis* Muir. Exp. Sta., H.S.P.A., Ent. Ser. Bul. 9, p. 9, 1910. Papua.
(12) *P. amboinensis* Muir. Exp. Sta., H.S.P.A., Ent. Ser. Bul. 9, p. 10, 1910. Amboina. *(P. fuscifrons* Muir. Exp. Sta., H.S.P.A., Ent. Ser. Bul. 9, p. 11, 1910. Amboina. This was later referred to *Dicranotropis.)*
(13) *P. insignis* (Distant). Ann. Mag. Nat. Hist., (8), IX, p. 190, 1912. India, West Africa (1 spec.).
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(15) *P. thompsoni* Muir. Proc. Haw. Ent. Soc. II, No. 5, p. 240, 1913. Guam.
(16) *P. bakeri* Muir. Philippine Journ. Sci., XI, p. 379, 1916. Philippines.
(17) *P. saccharivora* Muir. Philippine Journ. Sci., XI, p. 379, 1916. Philippines.
(18) *P. lineata* Muir. Philippine Jour. Sci., XI, p. 380, 1916. Philippines.
(19) *P. fuscipennis* Muir. Philippine Journ. Sci., XI, p. 380, 1916. Philippines.
(20) *P. pseudosinensis* Muir. Philippine Journ. Sci., XI, p. 381, 1916. Philippines.
(21) *P. manilae* Muir. Proc. Haw. Ent. Soc., III, p. 324, 1917. Philippines.
(22) *P. vitalisi* Muir. Ent. Mo. Mag., 61, p. 222, fig. 1, b., 1925. Indo-China.
(23) *Perkinsiella* sp., (unidentified, near *bakeri*). West Africa.

The Day-Degree in Mauritius

For the last few years we have been urging the use of the day-degree as a measure of effective warmth as it relates to cane growth.* It is, therefore, with great interest that we give here a brief review of an able paper by Pierre Halais of Mauritius† on the use of the day-degree.

Mr. Halais' contribution to the subject is that he suggests correction factors to the day-degree to take care of variations in the moisture content of the soil and the age of the plant. He contends that under Mauritius conditions cane growth does not take place below 20 per cent of soil moisture and that moisture above 40 per cent is of no use to the plant. He, therefore, assigns a value of 1 (100 per cent) to the upper limit of 40 per cent and 0 to the lower limit of 20 per cent of soil moisture. He

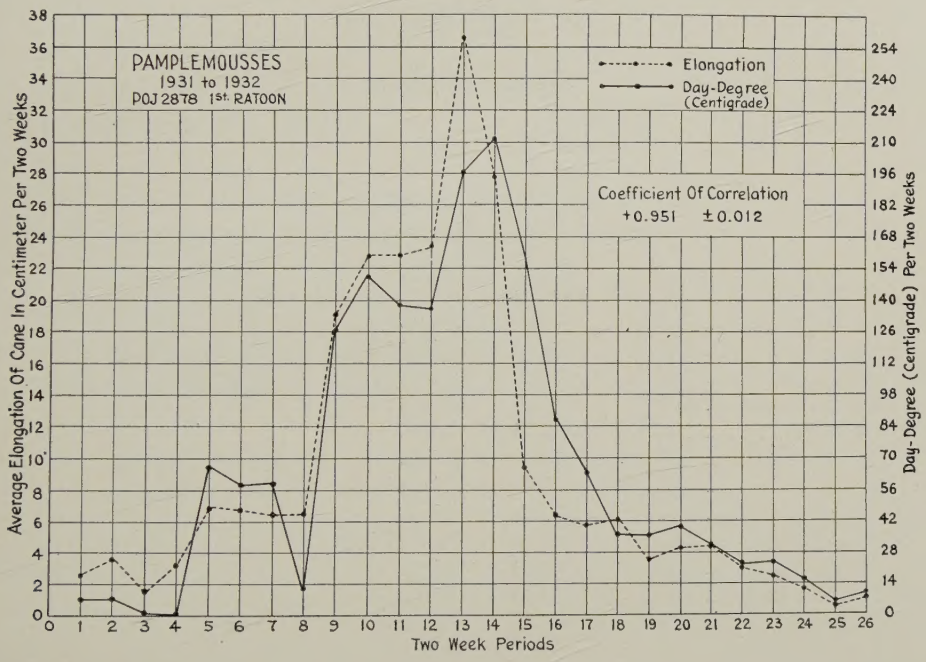

Fig. 1

uses linear interpolation between these limits, i. e., 30 per cent moisture is considered to have a value of 0.5, 25 per cent moisture a value of 0.25, and so on. The day-degree is then multiplied by these effective values. (We should note that his reasoning here is not in harmony with the experience of our irrigation experts.)

* See Agee, H. P., and Das, U. K., 1933. Proc. Ass'n Haw'n Sugar Tech., pp. 45-48, and Das, U. K., 1933. The Hawaiian Planters' Record, Vol. XXXVII, pp. 32 and 174.

† Un Nouvel Indice de Climatologie Agricole, La Revue Agricole, Maurice, No. 80, March-April, 1935.

He corrects for the age effect by assigning a value of 1 to the first-year cane before tasseling and 0.5 to the cane after tasseling. The day-degree is again adjusted accordingly.

In regard to the day-degree itself, he assumes that its value increases somewhat as the temperature rises above certain limits.

Employing the above corrections he finds a correlation of +0.95 between actual cane growth and the adjusted day-degree. A typical chart is reproduced below from his articles (Graph III).

Our purpose in bringing this article to the notice of our readers is not to recommend his methods, some of which are open to question, but to indicate that here lies a fruitful field of research for the plantation agriculturist—one that is bound to yield results of great practical value.

U. K. D.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
SEPTEMBER 16, 1935, TO DECEMBER 7, 1935.

Date	Per Pound	Per Ton	Remarks
Sept. 16, 1935	3.47¢	$69.40	Cubas.
" 17	3.45	69.00	Philippines.
" 23	3.54	70.80	Cubas, 3.55, 3.57; Philippines, 3.50, 3.55.
" 27	3.59	71.80	Cubas.
Oct. 2	3.65	73.00	Cubas.
" 4	3.68	73.60	Cubas.
" 14	3.60	72.00	Philippines.
Nov. 1	3.50	70.00	Cubas.
" 8	3.40	68.00	Puerto Ricos.
Dec. 4	3.10	62.00	Cubas.
" 6	3.07	61.40	Cubas.
" 7	3.10	62.00	Cubas.